# Energy Performance of Traditionally Constructed Dwellings in Scotland

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# ABSTRACT

This research was commissioned by Historic Scotland, to ascertain what, if any, characteristics specific to traditionally constructed (stone masonry) dwellings in Scotland could impact on the result of an energy assessment. The research uses five case study dwellings, whose energy consumption has been assessed using three separate calculation methodologies: the two Government-accredited steady state methodologies SAP and RdSAP, in addition to a dynamic simulation using the IES Virtual Environment. The research finds primarily that traditionally constructed dwellings use more energy than the UK average, and that certain aspects of the steady state calculation methodologies give erroneous results. These errors are either specific to stone masonry dwellings through application of assumptions with respect to thermal storage and movement, or specific to Scottish dwellings through application of UK average climate variables. Furthermore, there are significant challenges to using dynamic simulations for these dwellings, which may not outweigh the benefits of perceived accuracy by the occupant. Therefore, the research concludes that the steady state methodologies should continue to be utilised, but with the awareness that the methodologies have limitations.

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ACADEMIC REGISTRY

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TABLE OF CONTENTS

## Contents

LIST OF TABLES

LIST OF FIGURES

# LIST OF EQUATIONS

# LIST OF PUBLICATIONS BY THE CANDIDATE

Ingram, V. & Jenkins, D.P. 2013. “The UK’s Green Deal: a modelled case study impact review”.
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# GLOSSARY

**Appliances**
Includes cold and wet white goods such as fridge and freezer

**Building Regulations**
Rules concerning new and existing building projects produced by the UK Government, applicable to England & Wales

**Building Standards**
Rules concerning Scottish buildings produced by the Scottish Government, consisting of multiple Sections, each responsible for a certain aspect of building projects, e.g.: Section 4 - Fire; Section 6 - Energy

**Conservation**
The act or an instance of avoiding depletion or loss

**Domestic Hot Water**
The term used to encompass hot water at the taps, e.g for washing, showers

**Energy *Consumption***
The energy needed taking into account distribution losses and efficiency, e.g. the energy required to run the boiler to heat sufficient water for the demand

**Energy *Demand***
The energy needed at the end point, e.g. the energy needed for hot water at the tap

**Energy *Requirement***
The energy needed taking into account distribution losses, e.g. from un-insulated pipework

**EU Directive 2001/77/EC**
Renewable Electricity Directive: set an EU-wide target of supplying 12% of energy (including 22% of electricity) using renewable energy sources by 2010

**EU Directive 2002/91/EC**
Energy Performance of Buildings Directive (EPBD): requires a common methodology of energy assessment and implementation of energy certification of domestic and non-domestic buildings in all EU Member States

**EU Directive 2009/28/EC**
Renewable Energy Directive: includes all forms of energy not just electricity, proposes a 20% renewable energy contribution to final energy consumption

**Heat capacity**
The energy required to raise the temperature of a material by one degree

**Heritage**
The evidence of the past, such as historical sites, buildings, and the unspoilt natural environment, considered collectively as the inheritance of present-day society

**Historic Scotland**
The Government department in Scotland responsible for the care and protection of Scotland's historic and built environment.

**Infiltration**
Incidental air leaks into and out of the building envelope through defects in the construction. Combined with ventilation provides a measure of total ventilation losses

**Linear thermal transmittance**
The rate of heat flow per degree, per unit length, of a thermal bridge

**Listed Building**
In England & Wales, buildings are graded Grade I, II and II* (I being the highest). In Scotland, buildings are graded A, B and C, with A being the highest, and equivalent of English Grade I.

**Specific heat capacity**
Heat capacity for a particular layer within a material

**Tenement**
A traditional building type in Scotland. A tenement is one flat in a block of flats surrounding a central staircase, typically unheated, with a skylight overlooking the stair

**Thermal bridging**
A route of heat loss that occurs at junctions in the building envelope

**Thermal conductivity**
The amount of heat per unit time, per unit area, that can be conducted through a material of unit thickness, the sides of the material differing by one unit of temperature. Insulation providers typically quote the thermal conductivity of their products, the lower the value the better the insulation

**Thermal mass**
The ability of a material to absorb heat or cool. It is defined in SAP as the sum of (area × heat capacity).

**U-value**
The measure of the rate at which heat transfers through an element of construction

**Ventilation**

The act of air entering and leaving the building, either through natural means (open windows, air bricks, chimneys etc, or mechanical such as mechanical ventilation units that replace the air

# ABBREVIATIONS

| | |
|---|---|
| BRE | Building Research Establishment |
| BSD | Building Standards Division |
| CS | Case Study |
| DECC | Department for Energy & Climate Change |
| DHW | Domestic Hot Water |
| EED | Energy Efficiency Directive |
| EPBD | Energy Performance of Buildings Directive |
| GHG | Greenhouse Gas |
| HLP | Heat Loss Parameter |
| ICOMOS | International Council on Monuments and Sites |
| IES | Integrated Environmental Solutions |
| IES<VE> | IES's Virtual Environment |
| LEL | Low Energy Lighting |
| RdSAP | Reduced data Standard Assessment Procedure |
| SAP | Standard Assessment Procedure |
| SBEM | Simplified Building Energy Model |
| SEDBUK | Seasonal Efficiency of Domestic Boilers in the UK |
| SHCS | Scottish House Condition Survey |
| TFA | Total Floor Area (of the dwelling, over all storeys) |
| TMP | Thermal Mass Parameter |

## NOMENCLATURE

| | |
|---|---|
| $A$ | Area |
| $A_i$ | Area of each element *i* |
| $C_1$ | The correction factor for low-energy lighting outlets |
| $C_2$ | Correction factor for daylighting depending on the ratio of glass area to floor area, glass transmittance and light access |
| $c_m$ | Specific heat capacity of a material in IES |
| $E_B$ | Average annual energy consumption for lighting with no low-energy lighting |
| $E_L$ | Energy for lighting |
| $E_{Lm}$ | Energy for lighting in month m |
| $\varepsilon$ | Ventilation openings per meter exposed perimeter, taken as $\varepsilon = 0.003\ m^2/m$ |
| $f_w$ | Wind shielding factor, taken as $f_w = 0.05$ |
| $h$ | Height above external ground level, taken as h=0.3m |
| $H_{TB}$ | The heat transferred through thermal bridges |
| $\kappa$ | Kappa value, refers to the heat capacity of each construction in SAP |
| $\kappa_i$ | The heat capacity of a material *i* over area, $A_i$ |
| $\lambda_g$ | Soil type thermal conductivity, taken as clay with $\lambda_g = 1.5$ W/mK |
| $L$ | The total number of fixed lighting outlets |
| $L_{LE}$ | The number of fixed low-energy lighting outlets |
| $N$ | Number of people |
| $n_m$ | Number of days in month m |
| $P$ | Wall perimeter |
| $P_{tra}$ | Heat transmission through the envelope |
| $P_{ven}$ | Ventilation heat loss |
| $P_{dyn}$ | Dynamically stored heat |

| | |
|---|---|
| $P_{heat}$ | Supplied heat to the heating system |
| $P_{gain}$ | Heat gain from internal and solar radiation |
| $\Psi$ | Linear thermal transmittance |
| $R_A$ | Heat loss to floor area ratio |
| $R_f$ | Thermal resistance of the floor |
| $R_u$ | Factor to represent heat loss to an adjacent unheated yet internal space |
| $\Delta T_m$ | The temperature difference from supply to point of use of hot water drawn off the system in each month |
| $U_i$ | The U-value of each element *i* |
| $U_0$ | The original U-value of a construction if exposed, prior to internal factors applied such as $R_u$ |
| $U_w$ | U-value of wall adjacent to under floor space, taken as $U_w = 1.5\ W/m^2K$ |
| v | Average wind speed at 10m height, taken as v = 5m/s |
| $V_{d,average}$ | Annual average hot water usage in litres per day |
| $V_{dm}$ | Hot water usage in litres per day for each month m |
| *w* | Wall thickness |
| *y* | Thermal bridging |

# CHAPTER 1– INTRODUCTION

## 1.1 Background and motivation

As social and political will to reduce emissions of greenhouse gases (GHGs) increases, more onerous targets are applied in policy from international, national and local authorities. The Climate Change (Scotland) Act sets a target of reducing net GHG emissions by 80% by 2050.

Emissions from the residential sector are responsible for 15% of the total $CO_2$ emissions in Scotland. This is a significant proportion attributable to a single sector. During the recession and surrounding years, the construction sector has suffered with falling output; therefore the sustainability agenda focus is switching to the existing building stock. The introduction of Energy Performance Certificates (EPCs) in January 2009 in Scotland established energy assessment of dwellings, and combined with rising energy costs occupants have become more aware of the energy required to run their home.

Scotland has just over 2.3 million homes and of those, approximately 459,000 (19%) were built before 1919. These historic and traditionally built homes were built in a different climate (both socially and atmospheric) and pose different problems to reducing housing stock emissions than homes built later in the 20$^{th}$ century. They will play an important part in reducing existing building emissions, but care will need to be taken to conserve the character of the buildings.

As increased demands are put on the existing building stock to reduce its $CO_2$ emissions, adaptation and refurbishment actions may be inappropriate and detrimental to buildings; not only the appearance and historical significance, but also the technical performance. Resolving the potential conflicts between energy efficiency and building performance of traditionally constructed buildings is the main challenge faced by the sector.

There is a perception that old stone dwellings are hard to heat, expensive to run, cold and damp. This research aims to challenge that perception, on behalf of Historic

Scotland, using various methods of calculating energy performance to analyse a number of case study dwellings. As well as examining the dwellings, the research will examine the available methods of calculating energy performance, assessing whether the methodologies available can accurately account for the differing constructions used across Scotland's historic and traditional buildings, and the benefits they bring to the occupants.

## 1.2 Research challenge

With the intention of analysing the assessment methodology's abilities in accurately representing energy use in a dwelling, the steady state assessment methodologies must first be put into a usable format. This then enables values to be used within the calculation that software-based calculation would not allow, and therefore question the assumed values that the methodologies utilise. A major part of the project is therefore production of a bespoke spreadsheet in Excel.

Further complicating the creation of such tools also arises from the pace at which changes are made to the accredited calculation methodology – typically every six months.

## 1.3 Objectives

a) To investigate the challenges that Scottish traditionally constructed dwellings face with respect to energy assessment.
b) To establish whether steady state models can be used to predict energy use in a traditionally constructed dwelling.
c) To compare the benefits and drawbacks of using dynamic simulation models.

### 1.4 Outline of thesis

Chapter 1 contains the background and motivation for the research, the challenges overcome for the research, the objectives and an outline of what the thesis contains.

Chapter 2 is the literature review, analysing what research and publications currently exist in this field, and how they are similar or how they differ to this research. The review covers the background of the project, including the history of Scottish traditionally constructed dwellings, the heritage and conservation principles that accompany that; the policy that impacts on these dwellings and on the energy assessment methodologies used to assess them; the Scottish housing stock; construction characteristics such as materials and building envelope; energy use in the home; the impact of occupants on energy demand; the models that are to be used in this thesis, the input required for them and the output from them; and how this research fills the gaps in the literature.

Chapter 3 explains the methodology used in the research, introduces the case studies to be used and the calculation methodologies that are analysed and compared. This chapter also explains the use of meteorological information in the energy assessments.

Chapter 4 analyses the calculation methodologies on a case study by case study basis. Each case study has unique attributes (and challenges) with respect to modelling the energy demand, and these aspects are analysed.

Chapter 5 combines the results of Chapter 4 and analyses whether the findings from each case study are replicated across all five case studies. The outputs of the SAP methodology are analysed across the case studies, and focus is paid to particular aspects that are important to traditionally constructed dwellings, such as thermal mass and dwelling type.

Chapter 6 discusses the findings from the previous two chapters and introduces findings with respect to the original objectives.

Chapter 7 concludes the thesis, including a summary of the findings, some recommendations towards the current practice of energy assessment of traditionally constructed Scottish dwellings, energy assessment practice in general, and defines some future research that could be carried out.

The thesis ends with a number of Appendices. These include the difference between English and Scottish Energy Performance Certificates, summary sheets of the five case studies, summary sheets of four additional case study dwellings that were assessed in subsequent research.

# CHAPTER 2– LITERATURE REVIEW

## 2.1 Background

What follows is a review of material available concerned with the energy performance of traditionally constructed dwellings, in the context of this project.

Firstly, the background to the project is discussed, outlining the concept of heritage, its importance, and its connections with dwellings. The policy and information needed for decision making are also reviewed. There is a wealth of information available regarding the Scottish housing stock, this data is explained and summarised. Traditional construction materials are explained, with particular focus on the characteristics and significance of the building fabric; the concept of thermal mass is introduced and explained. An introduction to energy use within dwellings is provided, along with a review of literature researching the different energy users, incorporating the buildings, the equipment, and the occupants. This is followed by a review of human behaviour with respect to energy use: what choices they make, why, and how it affects energy use and therefore energy performance of the dwelling.

The largest focus of the project and therefore the literature review is that of the models used to assess energy performance. The point is made that reductions in energy use are only (primarily) possible once energy consumption patterns are understood, therefore models are required that accurately represent energy consumption. Comparisons of four major energy assessment models are made: the input variables, the level of precision and complexity involved, the type of results obtained from each, and the level of detail involved in the analysis.

Finally, the variables needed for an energy assessment have been summarised, in the form of identifying five case studies.

### *2.1.1 Scotland's Domestic Buildings*

The evolution of a dwelling from the first constructions aimed at protecting people or animals from the elements to today's modern dwellings can be followed looking at key moments in history, whether societal, religious, philosophical, economic or political. First and foremost, a building exists to protect the occupants from the elements. Buildings usually also have secondary purposes, such as learning, worship, work, recreation, manufacturing, or healing. Dwellings may also be thought of as places of respite, providing protection from others, providing relaxation, or somewhere to raise a family. Much of the following information comes from (Beaton, 1997), a text that clearly outlines the changes through time to the way buildings were built and designed, and the reasons for those changes.

Many events throughout Scotland's history have shaped the design of Scottish dwellings, from either the settlers moving here or the work undertaken by the Scots. The conflict against England led to a defensive or protective style of design, with animals predominantly put in the same building, either in another end of the house or on the ground floor with living quarters upstairs (Beaton, 1997). By the mid-15$^{th}$ century, styles of building changed as external influences were introduced from abroad, and stone architecture became increasingly seen in residential buildings. Throughout the period of new classicism, the building of defensive castles decreased while the building of palaces increased (Wilson, 2005).

One of the largest modifications to Scottish housing design was the Reformation in 1560, which led to an increase in the money spent on dwellings. As the Church no longer received state money, landowners had additional money available to spend, and it was spent on their buildings. Additionally, land previously belonging to the church was split up and distributed as small plots of land. The new landowners wanted to have buildings designed similarly to the larger homes lived in by the rich, but without access to similar levels of funding, they settled for either extending their existing homes, or building smaller versions of those owned by the rich. These 'tower houses' emulated the large defensive towers seen in larger more prestigious homes but were less about defence and more about privacy and comfort (Beaton, 1997).

The 1700s saw the beginning of the industrial revolution and a select few people became more wealthy. The shipping route between Glasgow and America took 20 days less than the London to America route, which encouraged traders to use the Glasgow route (Merchant City Glasgow, 2009), contributing greatly to Glasgow's wealth. The slave and tobacco trade with areas such as Virginia made traders a considerable amount of money, which was subsequently spent on homes as a method of showing off ones wealth. One example of such a home is the building that now houses the large Gallery of Modern Art in Glasgow, which was built as a town house for William Cunninghame, one of the most wealthy tobacco merchants (BBC, 2009).

Towards the middle of the 18th century, towns were being planned in detail before being built. The layout was very different to modern day winding cul-de-sacs and estates, and featured predominantly straight lined streets running perpendicular to one another (Beaton, 1997). Homes would open directly onto the street, and each plot would include land at the back of the house either for cultivation or animal rearing. As villages and towns grew, the demand for materials increased, and the number of quarries increased to meet demand. Before mechanised transport, local stone was used in all but the most important buildings and monuments, which would tend to use materials from further afield (Wilson, 2005). The use of local stone was dependent on the characteristics produced by each quarry, of which by 1860 there were more than 1,200 across Scotland. For example, the Hailes Quarry at Edinburgh produced thinly bedded laminated stone which was unsuitable for ashlar, but was heavily used in stairwells and landings in tenements (Wilson, 2005).

By this time, today's common sight of sash and case windows was well established. If repair work was demanded on existing buildings, architects would typically leave their own mark on the building, changing its features and in some cases making it look quite unrecognisable from before. These were the days before the philosophy of building conservation was thought of, and there was no consideration towards preserving or conserving built heritage (Earl, 2003).

During the 19th century many Highlanders and immigrants from Ireland moved to Glasgow for jobs after the Napoleonic wars and during the on-going industrial revolution (Wilson, 2005), but homes were not built quickly enough to house the increasing volume of people. The high density housing was not of high quality, and homes were divided to take more than one family in each dwelling (Begg, 1987). The low quality was accepted, and on completion of new homes those people displaced to make way for the new homes were not re-homed. The poor became packed in to increasingly poor quality and compact conditions. The volume of new accommodation needed led to advances in the methods of construction used, and saw Portland cement being used for the first time (Begg, 1987). The use of iron and steel also became common place, and the development of framed buildings began during the 20th century (Wilson, 2005).

While Glasgow was booming with the tobacco trade and export trade created through the Union with England in 1707, in contrast Edinburgh was cramped, overcrowded and dirty (in the area now known as the Old Town). James Craig designed the New Town to sit to the north of Old Town, and originally designed it to complement the new Union: the layout was a Union flag, although was later scaled back, and street names included Rose Street and Thistle Street to represent both England and Scotland. The majority of tenants were from the commercial classes – bankers, merchants and academics – and with no room for parks or large residences the aristocratic classes and working poor were excluded. Demand was high, and development of the western end was considered (Herman, 2003).

In the Lowlands, Robert Adam had learnt through his father's ownership and improvement of his building portfolio that architects make not only beautiful buildings, but they also make money. As the Renaissance style arrived in Scotland from London with its clean lines, grandeur and monumentality, Adam worked at Fort George as a builder, before travelling Europe. On his return, he came to introduce a neo-classical vernacular – elegance, sophistication, rise and fall, advance and recess, and flow with the surroundings. It was this philosophy he utilised in designing Charlotte Square, for the western end of Craig's New Town (Herman, 2003).

Outside the cities, conditions were improving. From 1840, the conditions for farm labourers improved as landowners provided them with small, rubble-built homes with two rooms, one for the family, and one for the animals: an example of how a dwelling can be functional. Similar functionality was noticeable in weavers' cottages, with living space on the upper floor and workrooms on the ground floor. Earth floors kept the room damp, which kept the thread supple and created better quality fabrics (Beaton, 1997).

At the end of the 19th century, Ebenezer Howard published 'Garden Cities of Tomorrow', a new ideal for town planning, where groups of houses would be placed around landscaped garden areas, ensuring each resident had access to green space. This publication led to the town of Letchworth, Hertfordshire, and following that success the idea was to be used for the new town of Rosyth, near Edinburgh. A new port was being built, and with it the need for homes for 3,500 workers, for which Howard's garden city plan was encouraged (Begg, 1987). By 1908 roads were being built in preparation, but by the time of World War I, not enough homes were completed and workers lived in cramped conditions. In 1915, the government passed the Housing (Rosyth Dockyard) Act to enable work to continue unchallenged, but by 1919 no more than 2,000 homes had been built (Begg, 1987). The town was eventually completed by 1930. This new town had an incredible impact on the house building industry, as to ensure completion new laws had been introduced such as the 1915 Housing Act, and the Town Planning Act 1909 (Begg, 1987).

### *2.1.2 Heritage*

The concept of heritage in the Scottish built environment typically takes on a view of castles and mansions in historic cities such as Edinburgh, Glasgow and Stirling, or small cottages built on a remote hillside. As will become apparent here, there is a much wider view of heritage to be had in Scotland, which will be explored and the change in the way that heritage is perceived will be explained. Where "heritage" is referred to, the more specific built heritage is implicit. For some people, heritage goes hand in hand with building conservation, but as this section explains, heritage can also be about preservation and sustainability, depending on how a building is managed, and the needs of that building and those living there. Rather than historic dwellings, this thesis focuses on dwellings of traditional construction built before 1919, and is not limited to listed buildings, but includes them as per the wider definition of traditional buildings (Loulanski, 2007).

There are many ways of defining heritage, and these definitions are constantly evolving and dynamic. As Loulanski points out (2007), the perceptions of heritage have undergone many changes in the last two centuries. As the number of stakeholders in heritage has increased, Loulanski argues that heritage has become more of a public than a private good, and that whereas during the 19th and 20th centuries the aim was to preserve objects of interest (protect the individual artefacts or buildings from decay and other forms of harm), during the latter half of the 20th century this moved to a desire to conserve, sometimes referred to as *purposeful preservation*: enabling the objects being protected to have current day use. This ultimately led to today's heritage concept, where objects from the past are now seen to have purpose and are subject to consumer demand (see Section 2.1.4).

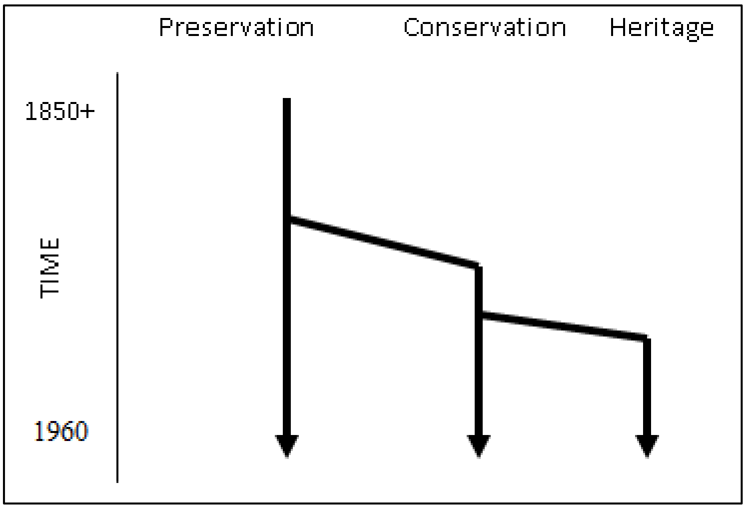


**Figure 2.1 The progress from pure preservation, through conservation, to heritage. Adapted from (Loulanski 2007)**

As objects are assigned value by people as a public good, this gives them significance and importance for a number of reasons, discussed below. Heritage can therefore no longer exist independent of human value, and therefore the definitions of heritage and its values will be constantly evolving (Loulanski, 2007). This view is in line with Harding's definition of cultural heritage as "an individual or group creation" of something that “becomes an important expression of human or cultural life” (Harding, 1999, p303).

If heritage cannot exist without human valuation, then it must also be that the changes in the definition of heritage come directly from human experiences and the culture of each generation. The concept of sustainable heritage, where future generations can have the same access to cultural heritage as the current generation have, relies on future generations wanting the same things and placing the same importance on something (Loulanski, 2007). Similarly, Burnett’s view of using heritage as a way of openly discussing human identity and social position (for example gender, ancestry or ethnicity) implies that future generations will want to continue to look backwards to previous generations (Burnett, 2000). This theory also relies on those in the future putting the same weight on a value as those today. Therefore, whilst traditionally seen as history, heritage is more a subject that lies within the present day, as it is created or destroyed by each generation.

The public’s perception of heritage can be defined by what they see in the media, and the:

> “News media still puts heritage in a box of a beautiful house or a beautiful painting, and doesn’t see it in its really broad sense, to do with culture, history and industrial history and landscape.”
>
> (Abramski, 2009)

The media will continue to shape how the public perceives heritage, with the choice of programmes commissioned, improved access to channels for the viewer, and most importantly, digitalisation will revolutionise how heritage is accessed (Hodge, 2009). The best case of this digitalisation movement is the addition of a number of heritage locations to Google Street View, both around the world and across the UK (National Trust 2010) including Lyme Park, Cheshire; Stonehenge, Wiltshire; Corfe Castle, Dorset; and Pompeii, allowing people across the world to virtually walk through the famous ruins. This demonstrates one way that people all over the world feel a need to connect and engage with cultural heritage, and further demonstrates that the heritage sector is constantly evolving.

Additionally, television and films play an important part in improving the public's access to, and understanding of, the built heritage. Series such as Channel 4's *Beeny's Restoration Nightmare* (aired 2010-2012) and the BBC's *Restoration* (aired 2003-2011) highlighted the challenges of restoring neglected houses, educated the viewers on the building's history and explored the values associated with built heritage explained below. The film industry has also boosted the public interest in the built heritage and history with films such as Pride & Prejudice and The Queen, whilst the Harry Potter series and films such as The Da Vinci Code have led to an increase in the number of visitors to locations used during filming (Edwards, 2007; Nickalls, 2003). As the public access to heritage changes so too will their views, ensuring that the concept and philosophies of built heritage continues to evolve through the 21$^{st}$ century.

### *2.1.3 Building conservation*

The philosophies behind building conservation outline the significance of the built heritage: what makes a building or feature important, and why. These philosophies and the concept of conservation date back to 1877 when William Morris and others began the Society for the Protection of Ancient Buildings (SPAB), wishing to halt the tendency at the time to 'scrape' the fabric of ancient buildings to aid restoration. Morris argued that the natural weathering and staining of the buildings was as much a part of the building as the building materials themselves and that scraping the external surfaces was detrimental (SPAB, 2009).

In 1931 the International Council on Monuments and Sites (ICOMOS) agreed the Athens Charter, outlining measures to be taken when restoring historical monuments (ICOMOS, 1931). Following World War II and the large scale destruction of property in the UK, lessons were learnt during restoration and reconstruction of many buildings of the importance of the built heritage. It was during this period that the listing and protection of buildings was introduced into the legal system through Town and Country Planning Acts.

During the 1960's and 1970's public concern for the control of pollution, damage to ecosystems, and the increasing consumption of the earth's resources increased in parallel with growing interest in the built and natural heritage. Out of this movement tighter planning controls were developed, and in 1965 ICOMOS agreed the Venice Charter, the first building conservation charter (ICOMOS, 1965). This was followed at the turn of the century by the Burra Charter (ICOMOS, 1999), internationally regarded as a base point for national agreements. In 2000, Historic Scotland published the Stirling Charter, setting out the principles to be followed for the conservation of the built heritage in Scotland. The Charter includes the principles behind building conservation and the wider sustainability agenda, and seeks to ensure the built heritage is acknowledged as an irreplaceable resource and managed in a sustainable way, securing the benefit and enjoyment of present and future generations. It recognises the value and significance of the historic environment, and asks that bodies such as Historic Scotland: provide guidance and encouragement to those who require it; ensure high standards are applied; effective monitoring and recording systems are established and maintained; and that due respect is given in all activities towards the built heritage. Additionally, the Charter requires that appropriate materials, skills and methods are used, and that conservation is based on sound knowledge and understanding of the site and its value, and that adequate consideration of significance be given to all elements not just the building as a whole (Historic Scotland, 2000).

To effectively use the Stirling Charter, the reasons why a building or its elements may be considered significant should be understood, of which there are many (Earl, 2003):

1. Celebratory and magnificent – the building is a work of art, e.g. Palace of Holyrood House, Edinburgh
2. Rare and curious - examples of living from the distant past, e.g. Skara Brae, Orkney
3. Commemorative and associative – a significant event, or a significant person lived there, e.g. Shakespeare's Globe theatre
4. Exemplary and instructive - symbols of a style, or embody architectural knowledge, e.g. St Giles Cathedral, Edinburgh
5. Pleasing and picturesque – the building or ruins add beauty to a landscape, e.g. Stonehenge, Wiltshire

6. Impulse to preserve – pride in a building or its aesthetics, e.g. New Town district, Edinburgh

In addition to the reasons behind significance, there are also motives for conservation. There are two main areas of conservation: replacing parts of a building that are decaying, and protecting those that would otherwise decay (Earl, 2003). This is tantamount to maintenance, and enables the building to remain in a manageable, habitable state. Effective conservation can improve the life and health of the building and its occupants.

The conservation of a building is very different to conservation of the planet and the two are often separate in the stakeholder's mind. A homeowner may be concerned with both climate and their home, but many will not be familiar with conservation principles and tend to adopt an 'if it's not broke, don't fix it' approach (Forsyth, 2007; University of the West of England, 2003). (The exception to this can be seen in buildings with thatched roofs, where good maintenance of the thatch and any chimneys notably reduces risks and costs over the building lifetime.) On the other hand, policy makers and officials within the building conservation sector may only be concerned with the building (Forsyth, 2007). This trend is however changing, as can be seen by the introduction of training for building conservation officers at Local Authority level, for example the Great British Refurb Workshop held in London (LSE, 2009) and increased coverage of the topic by industry bodies such as Changeworks, Heritage Link, and the National Trust.

The principles that underpin building conservation can be summarised as (Forsyth, 2007; English Heritage, 2008)

- Minimal intervention – work should only be carried out to the extent that it is no longer harmful to the value of the building
- Use of like-for-like materials – replacement materials should be physically and visibly compatible
- Reversibility of the work carried out – any changes made should be reversible to enable the building to be returned to an earlier state in the future

- Honesty and authenticity of the repair – repairs made should not 'trick' the observer, changes made should be obviously new, whilst matching the character and needs of the building
- Recognising the historic environment as a shared resource – all members of society should have access to the historic environment
- Sustaining the building's value – future generations should be able to get the same benefits and enjoyment from the historic environment as each generation before them
- Recording of all stages of the work – accurate records of maintenance, repairs and changes made should be kept for future evaluation of the building and its changing significance

### *2.1.4 Building value*

Just as building conservation is about maintaining the building fabric, it also about maintaining the building value. The value in the built heritage does not just lie in its history but in many, constantly evolving, aspects. There are five reoccurring values across the literature. As a baseline on which to build each concept, English Heritage (2008) outlines four areas of value: historical, evidential, aesthetic and communal. These are expanded upon and explained further here.

The historical value lies in not just a record of the past, but as a connection between the past and the present, and can be combined with evidential value to become *CULTURAL VALUE*, encompassing the archaeological and architectural value as buildings provide information on the form, structure and past techniques used, as well as being examples of particular styles, periods, or architects (Sanfilippo & Ngan, 2008). This also includes elements of scientific and technological value, as knowledge can be gained from good examples of particular construction techniques (Greffe, 2004), and the building form can provide information about community identity and demographic at the time of construction. For example, Blair Castle, Perthshire, has seen building alterations made across 700 years and as such can provide much evidence as to construction materials, values and methods during each period of alteration.

*AESTHETIC VALUE* stimulates people into having a positive reaction towards a building, is potentially the value noticed first, and may be greater with the finer examples of architecture and design. This value may be an emotional response or a sense of wonder at the symbolism or magnificence of a building, seen most commonly with palaces and temples, such as Culzean Castle, Ayrshire, or Balmoral, Aberdeenshire. It may also be through the rarity of the building, and a heightened level of curiosity towards it. Some buildings may become symbolic of a national identity and are therefore given value (Greffe, 2004). Good examples of this are the commonplace tenement flats seen in most urban areas across Scotland.

*ENVIRONMENTAL VALUE* encompasses many aspects, and considers the local and wider community in which the building exists. A building has value to the people who relate to it, whether the current occupants, the community, or those who have memories of past experiences. It can provide a sense of place, continuity and stability. It is this continuity and stability that enables heritage to play a vital part in providing social well-being of many different groups of people living in growing towns and cities that are becoming more cosmopolitan and uniform (Tweed & Sutherland, 2007). The sense of place can come from the way that buildings provide the shape for the area, the street layout and the look of place (Tweed & Sutherland, 2007), for example the New Town area of Edinburgh, or the Aberdeen bonding style of external masonry finish seen across Aberdeenshire.

As will be seen in Section 2.2 increasing emphasis is being placed on reducing the environmental impact of both new and existing buildings. Scotland’s traditionally constructed buildings may be in a prime position to provide important information on thermal comfort and energy use in one particular construction type – solid stone walled buildings. However, as seen at the Scottish Housing Expo at Inverness and the Housing Innovation Showcase (Scotland’s Housing Expo, 2010; Kingdom Housing Association, 2012), the use of stone in new building projects is limited, and where used is mostly aesthetic, either to create a specific look or as cladding to match the surrounding buildings. This limited use in new buildings means that the findings of this research will be limited to existing buildings, and may not be transferrable to new buildings.

Existing dwellings also provide environmental value in the form of embodied energy and carbon associated with producing the materials and constructing a dwelling. This would be lost and wasted if the dwelling was demolished, in favour of building a new, low carbon house. The Princes Regeneration Trust (Sanfilippo & Ngan, 2008) estimates that $CO_2$ emissions from repairing an existing building are far less than demolishing the building and rebuilding to current low energy building standards and research by Historic Scotland shows that natural stone is a low carbon building material (Chishna et al., 2010). Additionally, work by the Environmental Change Institute at Oxford University and the BRE, as summarised by Power (2010), highlights the complex nature of the *knock it down or do it up* debate, concluding that it will be better in both the short and long term to have a focus on improving existing buildings rather than demolishing them and building to modern-day low carbon standards. Adding credence to the *do it up* argument, research for the BRE highlighted that economic costs associated with demolition and new-build are higher than those associated with refurbishment (Plimmer et al., 2008).

The final value, and possibly the most significant, is therefore *ECONOMIC VALUE*. The built heritage can have direct economic value, by being a financial asset belonging to an individual or an organisation, or indirect value. The indirect value can be monetary, such as the contribution to employment or tourism, or non-financial, as a good that has no market value. Each of these indirect values is explained.

The historic environment is responsible for a sizable proportion of employment in Scotland, with 41,000 (full time equivalent) direct employees, and another 19,000 (full time equivalent) indirect employees (HEACS, 2009). If the numbers employed within the tourism industry related to the historic environment and the numbers employed in the built heritage construction sector are added to these figures, the historic environment is responsible for 2.5% of Scotland's total employment, and provides £1.4bn in employee income (HEACS, 2009). The jobs within the built heritage sector range from working for an industry body or governmental department such as Historic Scotland, through to construction, maintenance and repair roles.

In Scotland and the UK, tourism is a major part of the economy providing 37,000 full time equivalent employees and is worth £1.3bn with respect to Scotland's Gross Value Added (HEACS, 2009). A reported 1 in 10 visitors come to the UK because of what they have seen of our built heritage on film or television (Hodge, 2009).

## 2.2 Policy

### *2.2.1 Policy background*

The United Nations has been responsible for bringing together the countries of the world to understand and attempt to combat climate change, introducing a number of agreements giving each nation key objectives to strive towards. Phase 1 of the Kyoto Protocol was implemented in 1997 and ratified in February 2005, and called for a global 5% reduction in greenhouse gases by the period 2008-2012 over 1990 base levels (UNFCCC, 1998). Across Europe a burden-share was agreed so the 8% that Europe must achieve was divided unequally across the region, reflecting the different levels of economic development in each Member State. Therefore, the UK was required to reduce emissions of the six main greenhouse gases by 12.5% from 1990 levels, by the period 2008-2012 (House of Commons, 2009).

The most recent meeting at an international level took place in Doha, Qatar, in November 2012. At this meeting a long term strategy was agreed (Climate Connect Ltd, 2012): for a Kyoto Protocol "Phase II", with national targets to be set by 2015; a new post-2020 deal agreed by 2015; and implementation of a binding treaty by 2021. From a previous meeting in Copenhagen in 2009 it had been agreed that both developed and developing nations should work together to stabilise greenhouse gases at a level that will "prevent dangerous anthropogenic interference with the climate system", and that this level will be such that a global mean temperature rise of no more than 2°C is induced (UNFCCC, 2009).

The global-reaching Kyoto Protocol initiated a number of EU-wide policies designed to aid EU Member States in their efforts towards mitigation, such as the EU Renewables Directive, and the European Performance of Buildings Directive (EPBD). The EU

Renewable Electricity Directive (2001/77/EC) set an EU-wide target of supplying 12% of energy (including 22% of electricity) using renewable energy sources by 2010 (European Parliament, 2001). From this EU policy, the UK Government set a target of supplying 15% of energy by renewable sources by 2020 (BERR, 2008). In 2009, the Renewable Energy Directive was adopted, which included all forms of energy not just electricity (Directive 2009/28/EC), and proposed a 20% renewable energy contribution to final energy consumption (European Parliament, 2009).

The EPBD (Directive 2002/91/EC) was originally adopted in 2006, requiring a common methodology of energy assessment and implementation of energy certification of domestic and non-domestic dwellings, with a view to reducing energy consumption from buildings and improving energy efficiency of systems used (European Parliament, 2003). In November 2009 the EPBD was recast to make the targets in the 2002 Directive binding, to set minimum energy performance requirements, to include renovation projects on existing dwellings, to encourage net-zero carbon dwellings, and to further regulate energy prices and energy assessment methodologies (European Parliament, 2010).

The UK has national targets to meet as part of the EU targets and the Kyoto Protocol, and this includes the above renewable energy generation target. The introduction of policies with respect to climate change has led to energy policy as part of the mitigation effort. Reducing energy consumption is just one objective of energy policy: a second objective is towards the adaptation effort by maintaining comfort, health, and productivity levels, while raising energy efficiency and reducing energy consumption (Pérez-Lombard et al., 2009).

Whilst the concentration of energy consumption reduction efforts have been predominantly placed on new-build housing, 2009 saw a shift towards a focus on existing housing and the potential for improved energy efficiency. There are two main schools of thought: (i) that old, energy-inefficient dwellings should be demolished and replaced with modern constructed, more efficient dwellings; and (ii) that inefficient dwellings should be upgraded, whether through building fabric improvements, upgraded building services such as lighting and heating, or retrofitting renewable energy technology to reduce $CO_2$ emissions. "Knock it down or do it up?" was published in 2008 after investigating the two areas (Plimmer et al., 2008). The authors concluded there are three key reasons for retaining existing dwellings: the shorter timescale required to refurbish rather than demolish and rebuild; financial reasons including shorter contract and development duration; and environmental reasons. The environmental reasons include using more energy in demolition and rebuilding than the energy embodied within the existing dwelling and its emissions over its lifetime; and the location of a large proportion of old dwellings in city and town centres, reducing emissions associated with travel to work as journeys are walkable or available via public transport. Also considered were the building conservation values examined in Section 2.3, such as cultural, economic, environmental and societal values. When the authors investigated sustainability indicators amongst property professionals, they found the top three factors taken into account when considering refurbishment rather than demolition were heritage conservation, retention of communities, and satisfying market demand (Plimmer et al., 2008), indicating that property professionals place high values on the historic environment when decision making.

Scotland as a devolved nation sets its own regulations and targets that complement the UK laws on devolved matters. The Scottish residential sector is responsible for 15% of Scotland's emissions: in 2012 emissions from the residential sector in Scotland had increased by 2.7% over 1990 levels, up 14.6% from 2009 levels (Scottish Government, 2012).

The current Scottish targets have been introduced as part of the Climate Change (Scotland) Act implemented in August 2009 (Scottish Government, 2009), seen by many as the strongest climate-related legislation in the world having implemented the following requirements:

- An 80% reduction in $CO_2$ emissions compared to 1990 levels by 2050
- An interim target of a 42% reduction in $CO_2$ emissions compared to 1990 levels by 2020
- Annual targets set each year up to 2020 that require emissions to be less than the preceding year

- Annual targets set each year between 2021 and 2050 that require emissions to be 3% less than the preceding year

A separate but important objective set by the Scottish Government is to eradicate fuel poverty as far as is reasonably practicable by 2016 (Scottish Government, 2013). A household in fuel poverty is defined as a household that spends more than 10% of its gross income on heating the dwelling (Scottish Executive, 2001). Approximately a third of pre-1919 dwellings in Scotland are occupied by fuel poor households (Scottish Government, 2011), so this national target will affect a considerable proportion of the dwellings focused on in this project.

### *2.2.2 Building Standards*

As mentioned in Section 2.2.1 there has been a slow shift towards a focus on existing dwellings and the role they can play in reducing greenhouse gas emissions, particularly $CO_2$. It is estimated that 66% of dwellings in 2050 are already in existence (Boardman, et al. 2005), and it is fair to say that some of these will be the pre-1919 dwellings investigated here. It is also suggested that to reach the Climate Change (Scotland) Act target of an 80% reduction in $CO_2$ emissions by 2050, cuts of up to 80% in household emissions are also required (WWF, 2008).

As discussed in the previous section, Scotland has separate policies from England and Wales. With respect to energy in buildings there are similarities between England's Building Regulations and Scotland's Building Standards as the parent policy - the EPBD - requires a consistent methodology across all Member States, however, England's Building Regulations will not be explored here.

Building standards are continuously upgraded for both technical and political reasons. As energy policy strengthens and becomes more onerous, building standards must also be updated to reflect the changes (Woodley, 2009). For new build dwellings, gradual changes in Building Standards are bringing tighter control and tougher requirements for building fabric, construction quality, energy performance and energy efficiency (Scottish Building Standards Agency, 2009). For existing buildings the trigger for energy efficiency improvements is when extensions are built, and the improvements required are fabric-based for both the extension and the existing dwelling (Scottish Building Standards Agency, 2013).

Under the EPBD all dwellings require Energy Performance Certificates (EPC) when rented or sold. From 2018, all private rented dwellings (either in England & Wales only, or UK-wide) will additionally be required to achieve a minimum E-rating on the EPC before being rented (DECC, 2013) and the Scottish Government is currently consulting on a minimum standard for private and social housing, with consultation documents citing a minimum C or D-rating (Scottish Government, 2013a). The more recent Energy Efficiency Action Plan (EEAP) (Scottish Government, 2010) sets out actions for the Scottish Government that include:

- Encouraging behaviour change
- Challenging domestic energy efficiency barriers - such as financial, policy-based
- Research - the research described in this thesis is part of Historic Scotland's responsibility to traditional buildings, in understanding energy use in traditional homes
- Legislative – using the Building Standards to promote energy efficiency, as well as enforcement of standards.
- Ensuring planning policy allows solutions through permitted development rights
- Developing the skills needed for energy efficiency whether in construction, energy assessment, installation of refurbishments, procurement, planning or transport.

Any policy initiative must be assessed for its advantages (potential to succeed), and disadvantages. In many areas of policy that could impact on historic or listed buildings, a caveat is applied to ensure the conservation of the building.

### 2.2.3 Building conservation policy

As an executive agency of the Scottish Government, Historic Scotland introduces and implements policy to safeguard and promote the historic environment. A number of policies and aims have been produced, some of which are examined further below.

The Memorandum of Guidance (now superseded) concerned listed buildings and conservation areas, contained information on the reasons for designation, and the restrictions and allowances on work to listed buildings or conservation areas. The Memorandum also included potential reasons for conservation (of a building or area), which have also been discussed in Section 2.1.3, such as special architectural or historic importance, distinct character, value to the community, present condition and the opportunity for improvement or enhancement (Historic Scotland, 1998). Replacing the Memorandum is the Historic Environment (Scotland) Act 2011, which came into force in December 2011 (Scottish Executive, 2011). This Act was introduced to close loopholes that had been found in existing legal frameworks, and as such is much heavier on enforcement provisions and protection of the historic environment than previous legislation (Historic Scotland, 2013).

Combining the aims of the Stirling Charter (see Section 2.1.3), and the Memorandum of Guidance, Historic Scotland developed "Passed to the Future: Historic Scotland's policy for the Sustainable Management of the Historic Environment", outlining the role that Historic Scotland is to play with respect to managing the historic environment, and the key principles underlining its work (Historic Scotland, 2002). This document was replaced in 2008 with the Scottish Historic Environment Policy (SHEP), which took the principles of managing the historic environment to a more in-depth level and made the role of all stakeholders, not just Historic Scotland, much clearer (Historic Scotland, 2009). Among the principles delivered in the SHEP were that any change in the historic environment should be "managed intelligently", that conservation of the historic environment should be based on "sound knowledge and understanding of the site and its wider context", and that appropriate materials and methods should be used when working on such sites (Historic Scotland, 2009, p6-8). These are important principles to remember when looking at potential interventions to a dwelling.

With the introduction of the SHEP a number of interim guidance notes on ‘Managing change in the historic environment’ were introduced to outline how to apply the policies in the SHEP and Scottish planning policy. In 2010, the guidance notes were updated, followed by a SHEP update in 2011 (Historic Scotland, 2011). Whilst this project does not focus solely on listed buildings, the contents of the Memorandum and its successor documents are still important for the background understanding applied to this project’s research.

Historic Scotland works with a number of key stakeholder organisations and other executive agencies to ensure the best interests of the historic environment are being met. This includes working with English Heritage where possible, who provide similar services as Historic Scotland for England as the Government’s statutory advisor. Their ‘Conservation Principles’ guidance document is used in England to shape policies and guidance notes, and contains similar information and concepts to those of Historic Scotland (English Heritage, 2008).

## 2.3 Data Review

### *2.3.1 Traditional dwellings*

This project is concerned only with ‘traditionally built’ dwellings, which are defined as those with traditional construction built before 1919, and importantly, are not limited to listed dwellings or dwellings within conservation areas (Urquhart, 2007). Section 2.4 will discuss in more detail what constitutes traditional construction. This section will outline the importance of this type of dwelling.

There are approximately 459,000 pre-1919 dwellings across Scotland; approximately 19% of Scotland’s housing stock (Scottish Government, 2012b). Not all of these are of traditional construction, but there is currently not sufficient analysis of the housing stock to determine a numerical per cent. The majority of Scotland’s housing stock has been built within the last 100years, using very different methods as industrialisation and mass production changed construction methods and materials, as outlined in Section

2.1.1. Prior to 1919, the construction techniques and materials were relatively similar; hence the dwellings built pre-1919 are grouped together as one (see Section 2.1.1).

Dwellings built pre-1919 are not evenly spread throughout Scotland (Table 2.1) and different dwelling types are predominant in different areas. Across the whole housing stock, not exclusively pre-1919, cities tend to have a larger proportion of flats or tenements and rural areas have a high proportion of houses. For example, Edinburgh is 65% flats, while the surrounding county of Midlothian is 77% houses. Similarly, Aberdeen city has a fairly even 53/47% split just in favour of houses, while Aberdeenshire has a much higher 89/11% split in favour of houses (Scottish Government, 2012c). Housing energy performance in the different regions is important with respect to local authority climate mitigation policies.

**Table 2.1 Historic homes in Scotland's Local Authorities (LA), 2009-2011 (Scottish Government, 2012c)**

| Pre-1919 dwellings | | | Pre-1919 dwellings | | |
|---|---|---|---|---|---|
| | **000s** | **LA %** | | **000s** | **LA %** |
| Orkney Islands | 3 | 36 | Aberdeen City | 18 | 17 |
| Scottish Borders | 17 | 33 | Renfrewshire | 13 | 17 |
| Perth and Kinross | 21 | 32 | Fife | 24 | 15 |
| City of Edinburgh | 68 | 31 | East Lothian | 6 | 15 |
| Dumfries and Galloway | 21 | 30 | North Ayrshire | 9 | 14 |
| Moray | 11 | 29 | Midlothian | 5 | 14 |
| Angus | 13 | 26 | Clackmannanshire | 3 | 14 |
| Aberdeenshire | 26 | 25 | East Ayrshire | 7 | 13 |
| Glasgow City | 71 | 25 | South Lanarkshire | 17 | 12 |
| Argyll and Bute | 10 | 25 | Eilean Siar | 1 | 12 |
| Inverclyde | 9 | 23 | West Dunbartonshire | 5 | 12 |
| Stirling | 9 | 23 | East Dunbartonshire | 4 | 9 |
| Highland | 20 | 20 | Falkirk | 6 | 8 |
| South Ayrshire | 10 | 20 | East Renfrewshire | 3 | 8 |
| Dundee City | 13 | 18 | West Lothian | 5 | 6 |
| Shetland Islands | 2 | 17 | North Lanarkshire | 5 | 3 |
| **Scotland** | **454** | **19** | | | |

The discrepancy between the total number of pre-1919 dwellings in the Key Findings report (459,000 dwellings) and the Local Authority Breakdown (454,000 dwellings) are present in the official documentation and left here. It is suggested that the 5,000 dwelling difference is small in comparison to the total number of dwellings in Scotland, and therefore this difference is not investigated further.

### *2.3.2 Scottish House Condition Survey*

The Scottish House Condition Survey (SHCS) is an indicator of the shape of the housing stock each year across Scotland, carried out using occupant surveys and assessments of building condition. The split of dwelling types within the pre-1919 age band is outlined in Table 2.2.

**Table 2.2 Pre-1919 dwellings by house type (Scottish Government, 2012c)**

| | **Number (000s)** | **Per cent** |
|---|---|---|
| Detached | 100 | 22 |
| Semi-detached | 61 | 13 |
| Terraced | 63 | 14 |
| Tenement flat | 178 | 39 |
| Other flat* | 56 | 12 |

* Other flat types include 4-in-a-block, tower blocks and converted flats

As discussed in Section 2.2.1, fuel poverty needs to be minimised as far as possible by 2016. The pre-1919 housing stock in Scotland has significant problems with fuel poverty, with 30-34% of households in fuel poverty, dependent on the fuel prices used in July and October 2011 respectively (Scottish Government, 2012c).

Within the pre-1919 housing stock, fuel poverty is partially dependent on dwelling type. Households in detached dwellings experience fuel poverty the most significantly, and terrace housing the least, as shown in Table 2.3.

**Table 2.3 Pre-1919 dwellings suffering fuel poverty, by dwelling type (Scottish House Condition Survey, 2010)**

| Dwelling Type | Fuel poverty (%) | |
|---|---|---|
| | Pre-1919 | National |
| Detached | 61 | 34 |
| Semi-detached | 29 | 28 |
| Terrace | 25 | 25 |
| Tenement | 26 | 25 |
| Other flat | 33 | 28 |
| Pre-1919 overall | 35 | 28 |

There appears to be little difference between pre-1919 fuel poverty and the national average, except in detached dwellings which are more likely to be fuel poor if built pre-1919, suggesting dwellings built post-1919 could be more likely to be detached or other flats. The post-1982 age band includes the more recent new-build dwellings that since 2002 have had tighter Building Standards on energy, construction quality and air-tightness, combining to greatly improve the energy efficiency of the dwellings, and reduce the likelihood of being in fuel poverty. Since 1982, 43% of dwellings constructed have been detached dwellings (Scottish Government, 2012c). This could explain the low national average level of fuel poverty in detached dwellings despite a pre-1919 high level of fuel poverty in detached dwellings. This supposition is further strengthened by Table 2.4, which further highlights the lower likelihood of fuel poverty in newer dwellings.

**Table 2.4 How age of construction can affect fuel poverty (Scottish Government, 2012c)**

| Age of dwelling | Not fuel poor % | Fuel Poor % | Extreme fuel poor % |
|---|---|---|---|
| Pre-1919 | 66 | 34 | 12 |
| 1919-1944 | 66 | 34 | 9 |
| 1945-1964 | 69 | 32 | 8 |
| 1965-1982 | 67 | 33 | 8 |
| Post-1982 | 86 | 14 | 4 |

It could be hypothesised that traditionally constructed dwellings should not suffer from fuel poverty to the same extent as more modern methods of construction, due to the potential for lower heating demand from thermal mass in the walls (to be discussed in Section 2.4.4). The figures outlined above from the SHCS portray a different picture. However, as fuel poverty is a measure of heating costs divided by income, the problem may not be with the heating costs but with the income of the occupants. If further analysis on the pre-1919 housing stock were to be carried out, there may be a number of occupants who earn very little, and therefore whilst living in an energy efficient dwelling may still experience 'fuel poverty'.

The National Home Energy Rating (NHER) scheme rates a dwelling on the cost per square metre to run the dwelling, including heating, lighting, and appliances. The score used in the analysis of the 2011 data (used here) is 0 to 10, with 10 being excellent and 0 being poor (Scottish Government, 2012c). Table 2.5 shows NHER classifications according to the SHCS and the differences between the overall housing stock and the pre-1919 housing stock.

**Table 2.5 NHER scores across the Scottish housing stock (Scottish Government, 2012c)**

| NHER Score | National (%) | Pre-1919 (%) |
|---|---|---|
| Poor (0-2) | 3 | 9 |
| Moderate (3-6) | 32 | 51 |
| Good (7-10) | 65 | 40 |

Similarly to the fuel poverty statistics, the higher national average score for NHER can be in part attributed to the new-build housing (post-1982) which has been subject to Building Regulations and strict energy targets for a number of years, leading to 85% of post-1982 housing achieving a good NHER (Scottish Government, 2012c).

In addition to the National Home Energy Rating, the UK's Standard Assessment Procedure (SAP) was introduced in 1995 to standardise energy assessment across the UK. The SAP rating is a measure of the cost of fuel used to run the dwelling, but unlike the NHER scheme does not include the costs of appliances (BRE, 2010). The scale runs from 0 (poor efficiency, very expensive, high emissions) to over 100 (very efficient, low running costs, where 100 indicates net zero emissions). The method itself will be discussed in much greater detail in Section 2.7. The national mean SAP rating in 2011 (latest year available at time of writing) was 62.6, and the mean SAP for pre-1919 was 54.6 (Scottish Government, 2012c), further evidence suggesting that homes built pre-1919 are less efficient than their modern counterparts.

## 2.4 Construction

This section will review in depth the characteristics, history and usage of traditional construction materials.

### *2.4.1 Materials*

The materials used in traditionally constructed masonry walls are explained in Urquhart (2007a), and summarised here. Additional sources are cited where used.

The masonry walls of the type investigated in this project consist of thick walls (typically 600mm) made of solid stone, which give high levels of thermal mass, with render sometimes on the external edge of the wall. Dwellings built after the 16th century are likely to also have plaster on the inside edge of the wall, applied on a timber lath that consisted of thin strips of wood in a lattice pattern adjacent to the wall ('lath and plaster'). This type of wall is porous and highly permeable as it contains a high volume of absorbent materials in both the mortar and stone, allowing the moisture level in a room to be stabilised as moisture can travel into and out of the wall. This type of wall does not typically have a damp course or vapour checks or barriers, primarily to enable this moisture transfer through the wall. For this reason, less permeable finishes should not be used with solid stone walls.

Planning permission is not required when changing or adding insulation to walls, except where listed building consent or a building warrant is required (Changeworks, 2008). It is worth noting however, that even listed buildings may have changes made to them, as although the listing applies to the whole building, the reason may be because of a single feature, and if work carried out does not affect that feature or the building's character, then permission may be granted (Urquhart, 2007a). Adding insulation externally will change the view of the building and is not usually recommended (Changeworks, 2008). Insulating internally can impact on the size of the dwelling (National Building Specification, 2010), require moving electrical sockets and other services, and there must be no negative impacts on original features on the wall or ceiling, therefore internal insulation is typically only viable when the original wall lining is missing or needing replacement (Changeworks, 2008).

Roofs are traditionally constructed using slate, clay or stone slate and flags. Similarly to the walls, the roofs are permeable to a certain extent, with well-ventilated roof voids (Urquhart, 2007a). The current best practice standard for loft insulation is 270mm (DirectGov, 2010), with good practice levels put into new-build housing much higher (Millard Consulting, 2009), to provide the best possible barrier to heat loss through the roof. The main consideration when improving roof insulation is ventilation and moisture control (Changeworks, 2008).

There are two types of floor in traditionally constructed dwellings – solid floors in direct contact with the ground and suspended timber floors. Concrete floors were beginning to be used towards the end of the period of interest, from the early 20th century onwards (Urquhart, 2007a). Because the floor can act as a horizontal bracing membrane, the floor is usually the last place to be improved to minimise the risk of movement in the walls (Urquhart, 2007b). Walls in traditional buildings will not have damp proof courses, but adding one when making improvements to a building can be detrimental to adjacent building fabric. The same principle applies to adding damp proof membranes below floors (Urquhart, 2007b).

Where insulation is not present or in need of replacing or improving, insulation should first be applied to pipes, valves, boilers, hot water cylinders and hot water tanks to minimise heat loss from the hot water and heating systems (Princes Regeneration Trust, 2009). It is more important to insulate the roof (sloping ceilings and rooms in the roof space are difficult to retrofit insulation) than it is to insulate the walls or floors, which in traditionally constructed dwellings can be more damaging than insulating (Princes Regeneration Trust, 2009). Additionally there are balances to be made between retention of original features such as the original lath and plaster finish and retention of room size, and the need to insulate or improve air leakage, as typically insulation is added 25mm from the stone (Morgan, 2006).

### *2.4.2 U-values*

A construction's U-value is a measure of the rate at which heat transfers through it. Modern building regulations call for minimum standards of U-values for each part of a dwelling: wall, roof, floor, and openings (Scottish Building Standards Agency, 2013). This section will discuss the U-values of these parts in traditional dwellings.

The U-value takes into consideration the depth of each material and the location of the material within the wall, roof or floor. Traditional constructions are much simpler than modern constructions which have multiple layers comprising facades, insulation, cavities, structural layers, vapour barriers and wall ties. The research by Baker (2011) explains the structure within solid masonry walls, and identifies that the proportion of mortar to stone has a bearing on the U-value.

In current Building Standards, there are two criteria for the building envelope to meet (Scottish Building Standards Agency, 2013):

1. No part of the envelope shall exceed the stated maximum U-value of that individual element (e.g. a particular window)
2. The area-weighted average U-value of each element type must not exceed a stated maximum (e.g. the area-weighted average of all windows)

It is seen in Table 2.6 that traditional construction materials and methods do not meet modern Building Standard requirements.

**Table 2.6 Typical U-values for traditional construction compared to modern Building Standards**

| Part of building envelope | U-Value ($W/m^2K$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre-1919 construction | | Building Regulation maximum for new-builds | | | | | | |
| | | | **1985** [a] | **1991** [a] | **2000** [a] | **2002** [a] | **2010** [b] | **2013** [c] | **2013** [d] |
| | | | **UK wide regulation** | | | **Scotland** | | | **England** |
| **Wall construction** | | | 0.45 | 0.45 | 0.35 | 0.27 | 0.25 | 0.25 | 0.30 |
| (Sandstone) | 1.70 | [e] | | | | | | | |
| (Granite) | 1.40 | [e] | | | | | | | |
| (Party walls) | 0 | [f] | | | | | 0.20 | 0.20 | 0.20 |
| **Roof (pitched) construction** | 1.60 | [g] | 0.25 | 0.25 | 0.16 | 0.18 | 0.18 | 0.18 | 0.20 |
| **Floors** | 0.60 | [g] | 0.45 | 0.45 | 0.25 | 0.22 | 0.20 | 0.20 | 0.25 |
| **Windows** | 5.50 | [h] | n/a | 3.3 | 2.0 | 1.8 | 1.8 | 1.8 | 2.0 |

Notes:

[a] (Killip, 2008)

[b] (Scottish Building Standards Agency, 2010)

[c] (Scottish Building Standards Agency, 2013)

[d] (HM Government, 2013)

[e] (Urquhart, 2007a)

[f] Based on a solid wall. (BRE, 2010)

[g] (Energy Saving Trust, 2004)

[h] (Baker, 2008)

As seen in Table 2.6 above, maximum values for U-values have steadily been getting more onerous since the introduction of the first real Building Control regulations in 1985 under a pre-devolution UK, and followed by a number of revisions leading to the present day (Killip, 2008). As the understanding of buildings has increased, elements that are responsible for energy became more tightly controlled, and the changes above have occurred. Although there has been a weakening of maximum U-values in the latest Scottish Building Standards, there is potential for a jump in the future to use backstop values that are seen in Nordic countries, as those countries have much tighter building control and have much lower energy use (Sullivan, 2007; Scottish Building Standards Agency, 2009).

### *2.4.3 Windows*

The typical window type of pre-1919 dwellings is timber sash and case windows (Urquhart, 2007a), see Figure 2.2. Metal window frames became popular during the 20th century, as the techniques improved and slim but strong and non-combustible frames could be produced (Urquhart, 2007a). In a typical traditional sash window, the glazed area is 55% of the total window area (not just the visible window area), but contributes to 72% of the heat lost through the window (Baker, 2008).

**Figure 2.2 Traditional sash windows in a pre-1919 tenement in Edinburgh. Source: Vicky Ingram**

Much work has been done on measuring potential improvements to single glazed sash and case windows (Baker, 2008; Changeworks, 2010). Windows are given a high level of importance when investigating what can be improved in a dwelling as they are simple to replace with a high efficiency window. However, there are concerns with replacing single glazed sash windows, as traditionally seen in pre-1919 construction, with modern double glazed sash windows (Urquhart, 2007a). The primary concern is that of the external view of the window to those outside the dwelling. Where a mixture of new and existing windows is used, an uneven façade can be seen as modern windows use wider bars and modern glass is flatter and more reflective (Changeworks, 2009). To overcome this issue, there are companies that now specialise in reproducing traditional but double glazed windows, with the characteristics of single glazing but U-values similar to modern double glazing (Fountainbridge Windows, 2010). Contrary to popular opinion, there are no legal restrictions on replacing windows in a dwelling unless the building is listed or in a conservation area (Changeworks, 2008).

The Changeworks project "Energy Heritage" looked at many aspects of traditionally constructed tenement flats, providing information on the U-values expected from different types of window, identified in Table 2.7.

**Table 2.7 U-values of windows with various treatments (Changeworks, 2008)**

| Window type | U-value ($W/m^2K$) |
|---|---|
| Timber frame single glaze sash and case | 5.5 |
| As above plus draught proofing | 5.5* |
| As above plus secondary glazing | 2.3 |
| As above plus wooden internal shutters | 2.2 |
| Modern double or triple glazing (uPVC) | 1.3 – 3.1 |

* Draught proofing will not lower the heat loss through the window, but it will reduce the air leakage from around the window frame (see Section 0 below for more information).

Comparing Table 2.6 and Table 2.7 above, it is seen that traditional sash and case timber windows can meet the current Building Standard individual element U-value of $3.3W/m^2K$. However, the use of internal shutters to reduce the U-value can only work when the room is unoccupied as they block the natural daylight, and is therefore not the most suitable solution for continuous reduction of heat loss, although one worth noting for reducing heat loss at night when temperatures are at their lowest. The use of secondary glazing has the benefit of reducing heat loss, but care is required to ensure they are fitted sympathetically to the dwelling.

### *2.4.4 Thermal Mass*

Every building material has a U-value (the rate at which heat transfers through it), and a thermal mass value, which is the ability of the material to absorb heat or cool, store it, and release it at a later time (Wheatley, 2008). Materials with high thermal mass, or 'heavyweight', react slower as there is greater resistance in the material, while lightweight materials react much quicker, and their temperature follows the temperature of the air outside the building much more closely (Wheatley, 2008), see Figure 2.3.

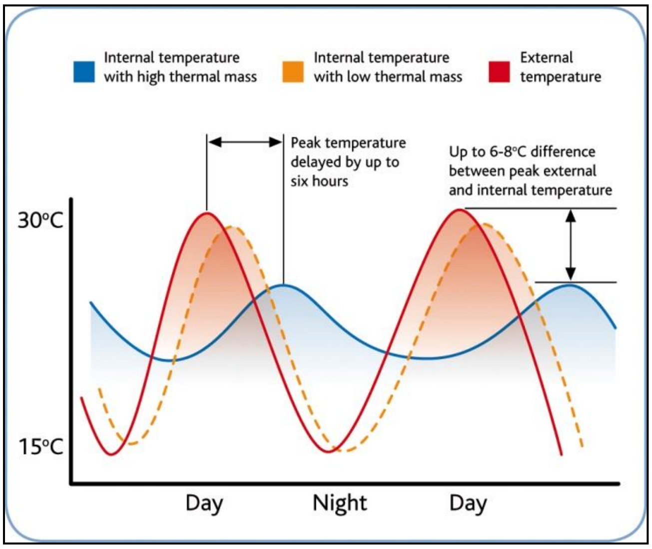


**Figure 2.3 Time response of materials with different thermal mass (The Concrete Centre, 2009)**

A research project for the Society for the Protection of Ancient Buildings (SPAB) identified the temperature profile of a number of wall constructions, with different materials and therefore thermal mass. The following figures identify the profiles, using sensors placed at various depths through the wall. The y-axis denotes the temperature, with the dotted line in each plot identifying 0°C. The x-axis denotes the depth of the wall from the external air temperature on the left to the internal air temperature on the right.

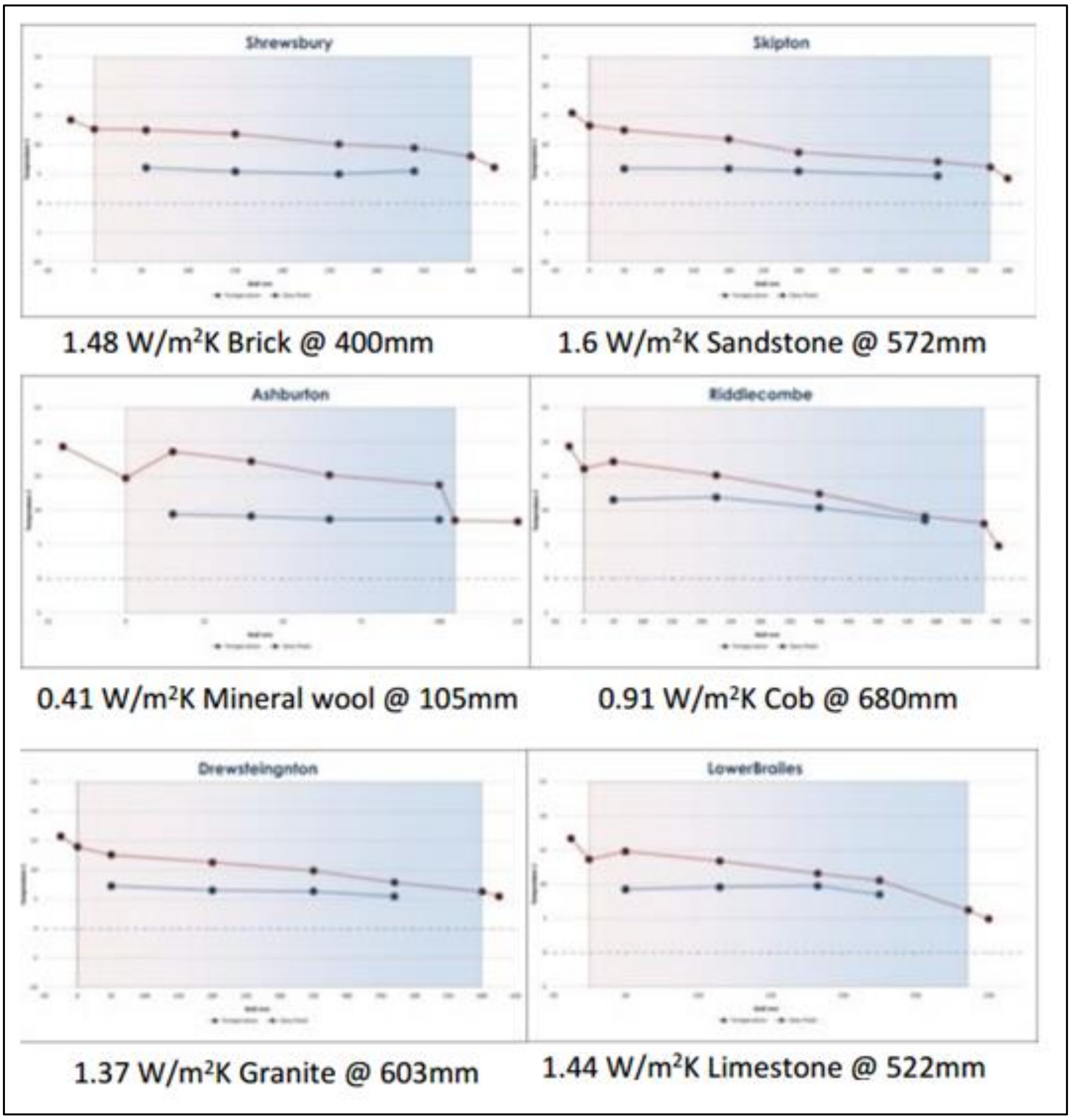


**Figure 2.4 14-day average temperature (red/top line) and dew point (blue/bottom line) profiles for 6 wall types. From (Rye, 2012)**

It is seen that the heavier-mass walls behave differently to that of cob, limestone and the insulation, with a more consistent profile.  This may be down to the homogeneity of the wall, or the insulating effect of the mass.

Three basic properties are needed for high thermal mass to be utilised (The Concrete Centre, 2009):

1) High specific heat capacity - to maximise the storage of heat absorbed
2) High density – to maximise the weight of materials used
3) Moderate thermal conductivity – to ensure that conduction of heat is synchronised with the diurnal temperature cycle

A summary of how these three properties combine with respect to thermal mass can be seen in Table 2.8.

**Table 2.8 Thermal properties of typical construction materials (The Concrete Centre, 2009)**

| Building material | Density ($kg/m^3$) | Thermal conductivity (W/mK) | Specific heat capacity (J/kgK) | Effective thermal mass |
|---|---|---|---|---|
| Timber | 500 | 0.13 | 1600 | Low |
| Steel | 7800 | 50 | 450 | Low |
| Lightweight block | 1400 | 0.57 | 1000 | Med-High |
| Pre-cast concrete | 2300 | 1.75 | 1000 | High |
| Brick | 1750 | 0.77 | 1000 | High |
| Sandstone | 2300 | 1.8 | 1000 | High |

In winter, the thermal mass absorbs heat from the room during the day, from sources such as heating, appliances, cooking, the people in the room, and solar gains from sunlight warming the surfaces and air in the room. During the night that heat is released slowly back into the room (Wheatley, 2008). In theory, the end result can be a higher internal temperature and a lower requirement for heating.

In summer, the thermal mass absorbs the same internal heat gains as in winter, with the exception of gains from heating, and the addition of increased solar gains from more direct sunlight during the summer months (Urquhart, 2007a). Theory states that thermal mass provides a cooling effect during the summer months by absorbing additional heat in the room, therefore windows can stay shut during the heat of the day to avoid infiltration of hot air (The Concrete Centre, 2006), although this must be coupled with ventilation at night (see Section 0 below). A second benefit of high thermal mass during the summer is related to the high thermal capacity: the structure can store a large amount of heat with only a small increase in temperature of the surface of the structure, providing occupants with a radiant cooling effect and therefore allowing a higher temperature to be tolerated than would be possible in a lightweight building (The Concrete Centre, 2009). This provides for a more comfortable living environment.

In order for the high thermal mass of a building to be useful in reducing heating demand by reacting with the internal heat gains, any insulation needs to be on the outside of the thermal mass. In solid stone dwellings this will not be a problem unless insulation is retrofitted internally (see Section 2.4.1 for further discussion on wall insulation). Internal finishes can be a benefit however. Adding plaster to a wall adds thermal mass to a wall so will not reduce its usefulness, and the use of quarry or similar heavyweight floor tiles also adds thermal mass to a structure (Wheatley, 2008). However adding thermal capacity is not the same as reducing thermal transmittance. Indeed, while the time lag of heat transfer increases linearly with mass per unit area, a mass-only approach is not a good indicator of the inertia of the material (Aste et al., 2009).

Due to the slow reaction times of heavyweight buildings, a heating system that is run for longer at low levels is more efficient, implying that heavyweight buildings should use smaller boilers that work at maximum output, and therefore maximum efficiency, hence encouraging lower $CO_2$ emissions (Wheatley, 2008). This impact on heating systems is also noted in Hacker et al (2008), who found that the $CO_2$ emissions from a heavyweight dwelling were sensitive to the heating schedule (either 24hour or intermittent). The Concrete Centre research (2006) also points to a typically higher use of heating in dwellings with high thermal mass when periodic rather than permanent heating is used. The research by Aste (2009) also found that heavyweight dwellings have lower heating demand when continuous heating is used. Similarly, BS 5250:2002 'Code of Practice for control of condensation in buildings' also encourages consistent heating in buildings with high thermal mass, to avoid problems with condensation when intermittent, purely convective, heating is used in a particular room or zone (BSI, 2005). Although, the BS 5250:2002 also states that radiators are well suited to buildings with high thermal mass due to their slow reaction time and their convective nature which can be disadvantageous for moving moisture through rooms, but is ideal for moving heat through rooms aided by the release of heat from the thermal mass (BSI, 2005). See Section 2.5.1 for further discussion on heating sources and emitters.

### *2.4.5 Air tightness*

All buildings require a certain level of ventilation to input enough fresh air to maintain a healthy atmosphere for both the building and its occupants. As fresh air enters the building it pushes warm stale air out the building. The higher the rate of transfer of air is, the higher the rate of warm air being replaced by cooler outside air. This causes the demands on the heating system to rise, and with it the emissions from the heating system. The air tightness of new-build dwellings is considered (but not regulated) within the Building Standards (Scottish Building Standards Agency, 2010), as part of the drive to reduce emissions from the residential sector. However, existing buildings do not have standards to meet with respect to air tightness, although work by organisations such as Changeworks is encouraging draught proofing to be carried out on older properties to reduce the energy demand of the dwelling (Changeworks, 2009).

With a very airtight dwelling, complications can arise, such as condensation, poor air quality, and overheating (Stephen, 2000). During the summer, buildings with high thermal mass need an element of ventilation, else the temperature will gradually rise to uncomfortable proportions as the building fabric continues to transfer heat inwards from the hot outside and the heat absorbed during the day. For effective cooling of the thermal mass, a diurnal temperature difference of at least 5°C is required (The Concrete Centre, 2006), and in the UK the temperature difference between night and day is typically 10°C, sufficient for effective night time cooling to take place (The Concrete Centre, 2009).

Ventilating the building is important if the benefits of thermal mass are to be fully appreciated (Wheatley, 2008). Non-domestic buildings typically have the luxury of being unoccupied at night and can be ventilated without disturbing occupants. However dwellings are typically occupied at this time. Traditional dwellings use natural ventilation, relying on differences in pressure and temperature to induce air flow between the inside and outside of the dwelling. The process of warm, moist air rising and escaping through chimneys, ventilation shafts or leaking through the roof area, and being replaced by cooler, drier air at low levels is called the ‘Stack effect’ and is most common during cold and calm weather (BSI, 2005). During more windy weather, the wind dominates, pushing cold fresh air in one side or drawing it in from the top, forcing the warm stale air out the other side. Typically, the stack effect and the wind dominance combine, to produce a flow of air through a house from the low level windward side, to the high level leeward side (BSI, 2005). Reliance on natural ventilation may have worked when these pre-1919 dwellings were built, with the appliances within the dwellings. However, it remains to be seen if modern day lifestyles, appliances and increased availability of hot water have introduced more water vapour than the dwelling can safely deal with using natural ventilation alone.

There is a balance to be struck between air tightness, reducing heating demand, and maintaining sufficient ventilation, important for moisture control and occupant health. Traditionally constructed pre-1919 dwellings can have the potential to be quite draughty, which seems initially like the primary problem to solve when wanting to improve a dwelling's energy performance as it can be achieved with relative ease and cost over other options. For example, Baker (2008) demonstrates that just draught proofing windows can reduce air leakage by 86%. Draught proofing also lessens the sound transfer between the outside and inside, and improves the perceived comfort of the occupants (Urquhart, 2007a). However, the ventilation needs of the building fabric must be taken into account and moisture levels not allowed to rise to prevent damage to the building fabric.

Thermal comfort is a measure of how occupants feel within a building (Wheatley, 2008). A significant factor in thermal comfort is the radiant temperature of surfaces (how much heat is radiated from the surface), in addition to the air temperature. As discussed in Section 2.4.4, theoretically a dwelling with high thermal mass will have lower radiant surface temperatures, and the occupants may be able to cope with a higher air temperature. As the climate warms, occupants' ability to adapt is likely to play an important role in how comfortable they are.

A concern for occupants as the climate warms will be overheating. Table 2.9 outlines the CIBSE definition of overheating. When using the UKCIP02 projections, CIBSE research finds that overheating is unlikely to occur in Edinburgh until the 2080s (CIBSE, 2005). Similarly, research undertaken using the same calculation methodologies as this research has found that overheating is unlikely to occur in Edinburgh by the 2030s: the research compared present day with the 2030s using the UKCP09 probabilistic projected climate (Jenkins et al., 2013). This implies that overheating is not likely to be a primary concern of Scottish householders in the near future.

**Table 2.9 Benchmark summer peak temperatures and overheating criteria (Adapted from CIBSE, 2007).**

| Area of dwelling | Benchmark summer peak temperature (°C) | Overheating criterion |
|---|---|---|
| Living areas | 28 | 1% annual occupied hours over operative temperature of 28°C |
| Bedrooms | 26 | 1% annual occupied hours over operative temperature of 26°C |

If it can be shown that dwellings with a high thermal mass are able to naturally maintain comfortable internal temperatures during warmer climates, then they will be important in demonstrating low energy means of adapting to a warmer climate (Hacker et al., 2008). When investigating overheating over the 21$^{st}$ century under the medium-high emissions scenario of the UK Climate Impacts Programme 2002 (UKCIP02), Hacker et al (2008) got results favourable towards dwellings with high thermal mass (in a dwelling in south east England). Firstly, they identified the year when the CIBSE definition of overheating was met (see Table 2.9 above), and found that in lightweight dwellings this occurred in 2021, and in heavyweight dwellings this may not occur until 2061. Secondly, as expected from Section 2.4.4, Hacker et al found that temperatures in the lightweight dwelling peaked at 5°C higher than in the heavyweight dwelling (Hacker et al., 2008). These findings mirror those found by the Irish Concrete Federation in their investigations into occupant comfort (Walsh et al., 2006). Furthermore, a study completed in Greece found that whilst a stone-built dwelling was less airtight than a brick-built dwelling, it was able to keep the indoor temperature lower than the external temperature (Sfakianaki et al., 2008). While these case studies were in Greece and experienced much higher external temperatures than currently experienced in the Scottish climate, it is a further demonstration of the benefit of high thermal mass in aiding cooling and improving thermal comfort of occupants.

As the climate warms the benefit of high levels of thermal mass decreases unless adaptation measures are implemented to enable sufficient night time ventilation (CIBSE, 2005). High levels of thermal mass without night time ventilation can increase the risk of overheating in new-build dwellings with high levels of insulation and air tightness (Orme & Palmer, 2003), it remains to be seen if the same problems will occur in traditionally constructed existing dwellings. Whilst the high thermal mass can provide a more comfortable daytime temperature, the slow response time to changes in air temperature can lead to warmer night time conditions as the mass is slow to respond to the ventilating cooler air (Hacker, 2005). As mentioned above, for thermal mass to be beneficial a diurnal temperature variation of at least 5°C is required, and the UK diurnal variation is approximately 10°C. Although average temperatures are expected to increase, the temperature difference between day and night should be similar to that experienced today (The Concrete Centre, 2009).

Some academic writing towards thermal mass in buildings focuses on non-domestic buildings. One such paper uses an office building with high thermal mass, and models potential future internal conditions using climate predictions from the UKCIP02 scenarios. The paper showed that high thermal mass has some benefit in maintaining comfortable internal temperatures as the external temperature increases. However, the paper also showed that mass alone cannot ensure an acceptable internal temperature when the outside temperature is so hot that the rooms become unbearable (Holmes & Hacker, 2007). It is argued that while the general findings with respect to the use of mass may be applicable to the domestic sector, the research's unique findings are not. The research for the paper will have included the heavy use of electrical equipment as seen in an office environment; additionally the inputs to the calculations will have been based on office occupancy (times of day, heating regime, activity, number of occupants).

## 2.5 Domestic Energy Use

All of the following sub-sections discuss the energy use associated with a dwelling. Each aspect of energy demand is significantly affected by the occupant's behaviour, which will be discussed within each section. The technical aspects of each section with respect to energy performance calculation will be examined in greater detail in Section 2.7.

### *2.5.1 Heating*

The way that dwellings are heated has changed over the centuries, while the concept has stayed the same: heating the dwelling to protect the occupants from the cold external weather conditions. The first dwellings relied on good construction to keep the elements out and radiant heat sources to warm the internal space, but today's combine keeping the elements out, keeping the heat in (minimising heat loss), and providing a source of heat to every room, typically through central heating systems.

Energy for space heating accounts for 60% of UK residential energy consumption, rising steadily from the 1970s with a slight fall between 2004 and 2009 (Palmer & Cooper, 2012; DECC, 2012). The carbon emissions associated with space heating depend heavily on a large number of variables, indicated by the ten pages of variables listed in the Appendices of the assessment model, including four fuel types, twenty four types of heating sources, seven types of heating controls, and a wide range of efficiencies from 45% to 300% (BRE, 2010).

Different constructions will require different heating strategies. It is recommended that dwellings with high thermal mass use constant low levels of heating (Section 2.4.4). If occupants are unaware of the benefits of thermal mass, it could be inferred that incorrect use of the heating will lead to higher bills and higher emissions, giving occupants the impression that the building is difficult to heat, when in reality, a change in heating regime could lead to lower bills, and a more comfortable living environment.

Since 1970, average internal temperatures in the UK have risen (see Figure 2.5), which is also an explanation of the increase in the energy consumed towards space heating, also shown in Figure 2.5. This is an excellent example of how occupant behaviour can affect the energy use of the building.

There are many different types of controls that can be used with a heating system: some that take control away from the user, and others that give full control to the user. Most central heating systems have at least a timer, to enable the user to set what times during the day they wish the heating to be on. Some systems will also have thermostats, so the emitters will only warm to a certain temperature. More advanced controls, which have the potential to reduce energy demand include:

- Zonal temperature control – a pre-defined zone from as simple as each floor, to as complex as each room, having a different thermostat temperature
- Frost protection – automatically turns the heating on when the external temperature reaches a pre-defined temperature, to protect the pipework from freezing. Therefore users can go away without leaving their heating on, whilst protecting against frost damage.
- Smart control – users can pre-programme periods of absence, the control will automatically turn the heating on the day before the user returns. Therefore no energy is wasted heating an empty house, but thermal comfort remains for the occupants returning.
- Weather compensator – an external temperature sensor is used to automatically alter the temperature of the water flowing through the heating system when the exterior cools or warms.
- Load compensator – an internal temperature sensor is used to automatically alter the temperature of the water flowing through the heating system.

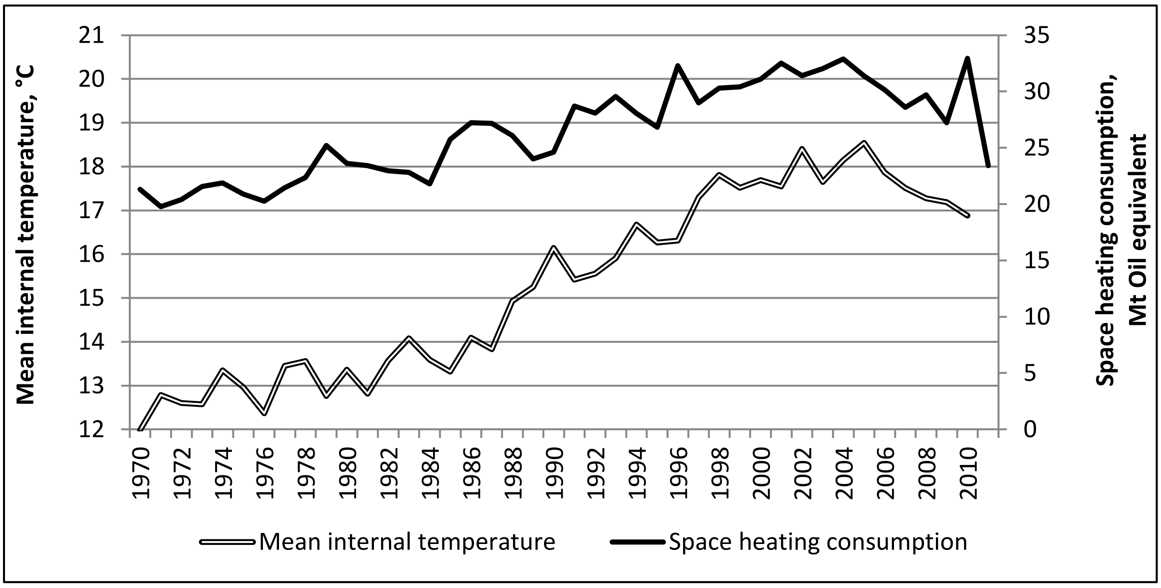


**Figure 2.5 Relationship between increase in internal temperature, alongside increased energy consumption for space heating (DECC, 2012)**

It may be that space heating consumption has seen a general increasing trend since 1970, but it is worth noting the trend, or lack of, towards costs of heating. Despite the rising fuel costs *per unit* since 2003, the proportion of household spend for heating has actually decreased since 1970, to 4.4% of total household spend (Palmer & Cooper, 2012).

### *2.5.2 Lighting*

Before the introduction of electricity, occupants used natural daylight hours to complete their tasks: the large sash and case windows that provide large amounts of daylight were well established by the 18th century (Beaton, 1997). Today's occupants however use energy to artificially light spaces to enable rooms to be used after dusk. The energy used to light dwellings accounts for approximately 19% of domestic energy consumption, and has more than doubled since 1970 (DECC, 2012). The average energy consumption for lighting is assumed to be 9.3kWh/$m^2$ per year if no low energy lighting is used (BRE, 2010), assuming fixed lights only. If low energy light bulbs are used this would be less, but if additional lamps or lighting are used this could be more.

Lighting in dwellings consists of either fixed fittings (for example ceiling lights) or the unfixed lamps that occupants add to the dwelling themselves. Energy performance models have no way of knowing what lighting has been added and therefore cannot accurately predict the energy demand.

The Building Standards that affect lighting do not apply to existing dwellings, or when alterations are made, however an extension would have to comply by at least 50% of the fittings being low energy with a luminous efficacy at least 40 lumens/circuit watt (Scottish Building Standards Agency, 2010).

The occupants of the dwelling will greatly affect the energy used for lighting, as they control the period of time when the light is on, whether lights are left on when occupants aren't in the room, or the level of light occupants require for different activities.

Light bulbs are seen as one of the easiest and cheapest measures that occupants can implement to change their energy bills, and the move from standard light bulbs to energy saving has been steadily increasing since the 1980s (Figure 2.6).

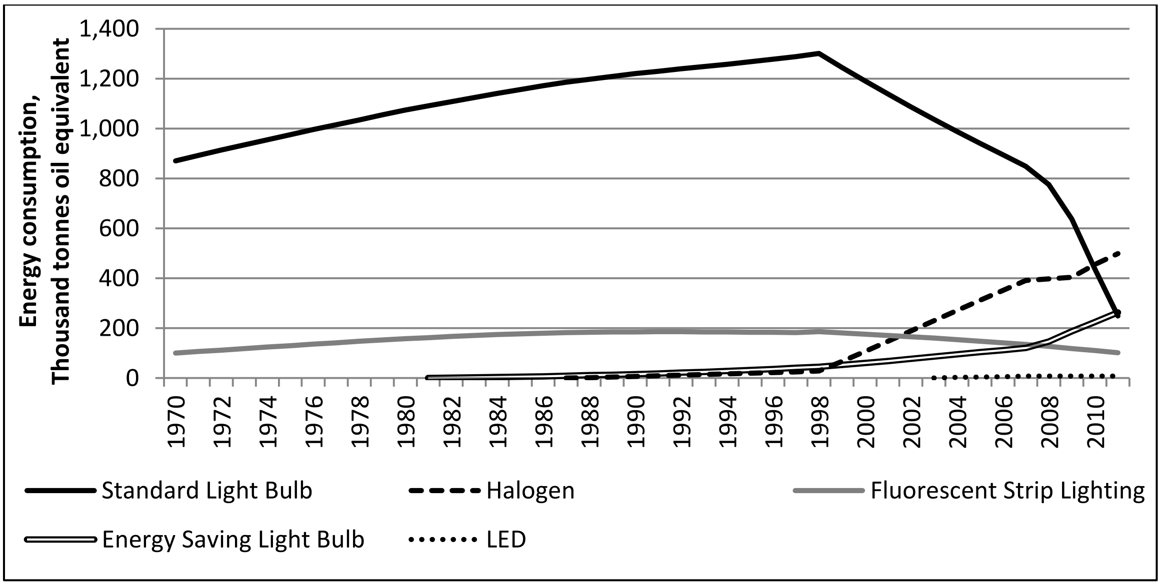


**Figure 2.6 Trends in light bulb use since 1970, across five bulb types (DECC, 2012).**

Many local authorities now provide homeowners with free energy saving bulbs, and suppliers are providing them at very low prices, giving homeowners payback within the first year (B&Q, 2010). In 2007, the UK Government announced a voluntary initiative to scrap the manufacture of standard light bulbs over a number of years (Table 2.10). The EU has also set similar targets (Table 2.11).

**Table 2.10 UK phase out of standard light bulbs (Energy Saving Trust, 2009).**

| Type of light bulb | Participating retailers to stop sales |
|---|---|
| 75-100W A-shaped | Jan 2009 |
| 60W A-shaped | Jan 2010 |
| 40W A-shaped | Jan 2011 |
| 60W golf ball-shaped and candle-shaped | Jan 2011 |

**Table 2.11 EU phase out of standard light bulbs (Energy Saving Trust, 2009).**

| Stage | Date | Main result |
|---|---|---|
| 1 | 1 September 2009 | • Clear lamps equivalent to 100W incandescent lamps, or above, must be minimum C class.<br>• Non-clear (frosted/pearl) lamps must be minimum A-class.<br>• Introduction of functionality requirements on lamps. |
| 2 | 1 September 2010 | • Phase-out of 75W clear incandescent lamps.<br>• Introduction of information requirements. |
| 3 | 1 September 2011 | • Phase-out of 60W clear incandescent lamps. |
| 4 | 1 September 2012 | • Phase out of all remaining clear incandescent lamps (i.e. 40W and 25W). |
| 5 | 1 September 2013 | • Enhanced functionality requirements |
| 6 | 1 September 2016 | • Raising the minimum level to B class for clear retrofit lamps (i.e. phasing out C-class retrofit halogen lamps). |

### *2.5.3 Domestic hot water*

Water use affects energy demand through the use of electric showers and the energy required to heat Domestic Hot Water (DHW). As well as providing hot water for daily use, the hot water system must also protect occupants from Legionella by heating any water in the system to at least 60°C, the temperature at which the Legionella bacteria dies.

Similar to space heating, a number of variables affect the energy required for DHW in the SAP calculation, including fourteen types of heater with varying efficiencies, methods, and fuel types (BRE, 2010). Domestic hot water (DHW) accounts for 18% of domestic energy consumption in the UK (DECC, 2012). In the last 40 years, the contribution of DHW to total energy consumption has decreased by 5%; however the energy consumed has increased by 14% (Figure 2.7). This could be due to increased use of DHW, whilst using increasingly efficient boilers.

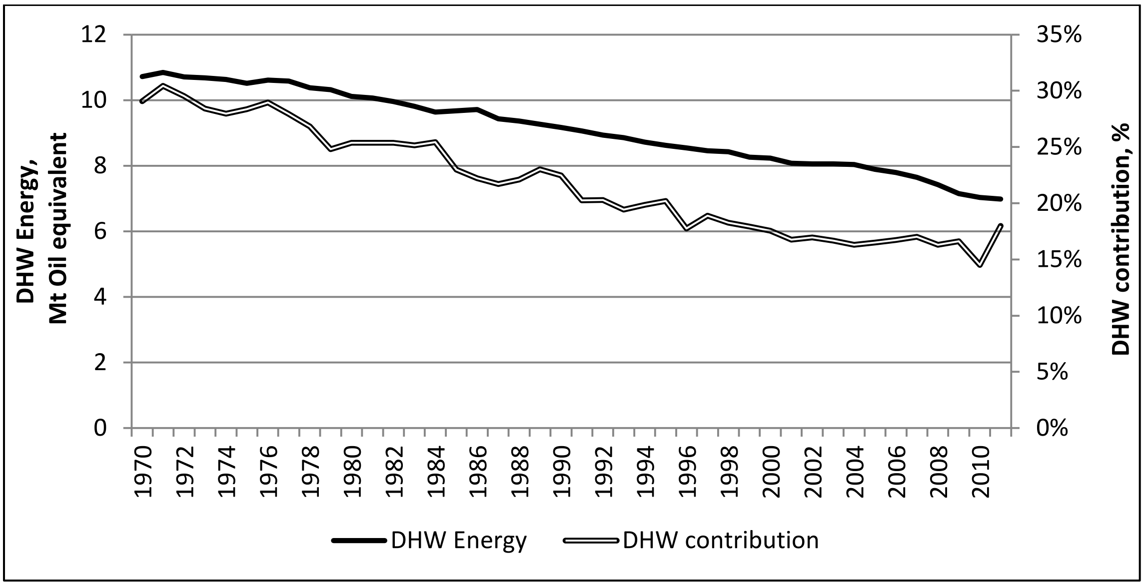


**Figure 2.7 A comparison of the energy used for DHW across the UK, and its contribution to overall total domestic energy consumption (DECC, 2012).**

### *2.5.4 White goods*

Large white goods, such as fridges, freezers, washing machines, tumble dryers, dishwashers, microwaves and ovens are all considered white goods, and add a significant energy demand to a dwelling. Whilst the energy efficiency of these units is not yet regulated, each unit when sold must have an energy label, following EU legislation, in a bid to make these items more efficient. The scale of energy efficiency runs from A (most efficient) to G (least efficient), with the exception of refrigerators. Refrigerator manufacturers have improved efficiency of their units to the point where all units now fit within the A band, and hence additional bands of A+ and A++ have been adopted (Energy Labels, 2004). For example, in 1990 a new refrigerator would consume 311kWh/year; in 2011 that had fallen to 169kWh/year, similar advances have also been made among freezers (DECC, 2012).

Whilst units have become ever more efficient the number of units in use has increased. The DECC data (2012) from 1970 to 2011 shows a steady increase in the number of white goods, from approximately 23.6 million units in 1970 to just over 88.2 million units in 2011. However, a three-fold increase in the number of units equates to little over a two-fold increase in the electricity consumption, such is the extent of the energy efficiency improvements made by manufacturers (DECC, 2012).

### *2.5.5 Cooking*

The energy used for cooking in a domestic situation accounts for 3% of total UK energy consumption (DECC, 2012), and is largely dependent on the occupants; the associated carbon emissions are dependent on the fuel source used, predominantly electricity and gas.

As seen above in Section 2.5.4, the EU Energy Labelling scheme has had some success in improving the energy efficiency of white goods, including ovens. As Figure 2.8 shows, there has been a steady decrease in the proportion of total energy use that cooking is responsible for. However, the actual energy consumption for cooking shows no discernible trend, which implies that the decrease in proportion of energy used for cooking is perhaps more likely due to increasing total energy use, rather than a decrease in cooking energy and/or increase in cooking appliances efficiency.

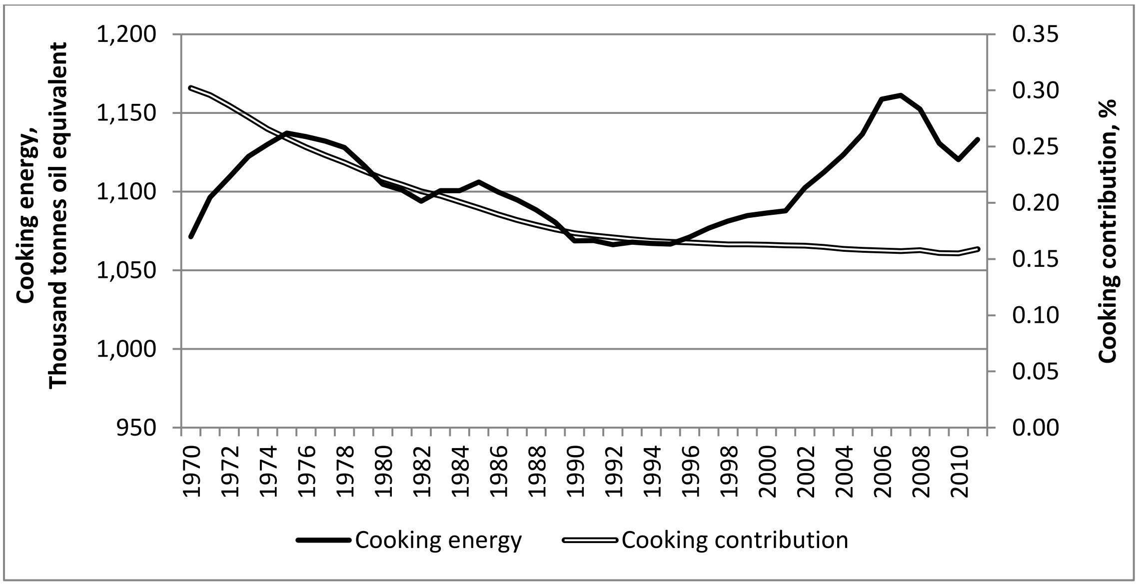


**Figure 2.8 The contribution of cooking to total UK domestic energy consumption (DECC, 2012).**

### *2.5.6 Appliances and equipment*

A further example of domestic energy consumption heavily dependent on the occupants and their behaviour is the energy consumed by appliances and other electrical equipment, and this is discussed further in Section 2.6.

## 2.6 Occupancy

As introduced in Section 2.5, the occupants of a dwelling can play a significant role in determining the energy consumption of the dwelling. This section will discuss these points further and establish the importance of knowing the effects of occupancy behaviour. The modelling of occupants effects will however be discussed in Section 2.7.

Homeowners can be accused of using a "if it's not broke, why fix it?" approach to maintenance (Forsyth, 2007), which can not only be detrimental to the building fabric and its heritage, but can also impact on the energy performance of the dwelling. Poorly maintained heating and hot water systems can run at much lower efficiencies than they are designed to, and increase the cost, energy consumption and associated carbon dioxide emissions of the dwelling. Some homeowners living in historic (not necessarily traditionally constructed) dwellings feel that repair and maintenance are transposable and that the heritage value in the dwelling can be protected through repair and replacement rather than preventative maintenance (Forsyth, 2007).

Today's occupants could be expected in some respects to adapt their behaviour to match that required by the dwelling construction style, bringing together the behaviour of the pre-1919 occupants, with today's typical behaviours. However, it may be that the pressure on occupants to conform to today's energy-intensive culture is too significant and that a clash of the two cultures provides occupants with a high cost of living and a less than ideal living environment, in terms of both temperature and air quality. For example, traditional tenement flats have large windows, providing good levels of natural daylight, but modern convention says that electrical lighting will still be used, either because it is what the occupant is used to, or because the amount of light available is insufficient for a particular task. It is an interesting question as to whether or not living in traditionally constructed buildings forces occupants to behave in a manner very different to the behaviours seen in modern low-energy dwellings, but this is not explored in this thesis.

### *2.6.1 Occupant awareness*

A key message from many heritage sources when investigating the issue of whether to retain the use of traditionally constructed dwellings is that there is a wealth of information available to owners and occupants of these types of buildings. However, what is less clear is how to disseminate that information. Building professionals are aware of the role of organisations such as Historic Scotland, Changeworks, and the Energy Saving Trust in providing a knowledgebase on traditionally constructed dwellings, and their collaborative work. However, the public are possibly less aware of these organisations and the advice they can provide on lowering bills, energy consumption and $CO_2$ emissions. Only in the past few years has large scale television advertising been taken up by the likes of Natural Scotland (Info Scotland, 2010), British Gas (2010) and EDF Energy (2008). Besides getting the public to the right place for information, the public may also not know that they need the information. Unless a homeowner is actively trying to find advice they are unlikely to search for the information without some sort of trigger.

Occupants may become more aware of their circumstances and more able to make educated choices about their lifestyle as Government targets and strategies are implemented. For example, the Department of Energy and Climate Change (DECC) target that every home in the UK (where practical) will have loft and cavity wall insulation by 2015 (DECC, 2010), will undoubtedly be noticed by homeowners and may stimulate curiosity as to what other changes can be made in their homes.

### *2.6.2 Adapting*

Dwelling occupants are very good at adapting to changes in temperature and conditions without resorting to using energy: adjusting clothing and posture, opening/closing windows, window coverings, or fanning themselves (Rijal et al., 2008).

The high levels of thermal mass in traditional construction offers additional help to occupants by helping to maintain a more consistent and comfortable air temperature, and therefore requiring less use of energy to cool or warm the occupants (see Section 2.4.4). However, during the summer, dwellings with high thermal mass do need night-time ventilation, to retain the effectiveness of the thermal mass (Wheatley, 2008). This is another example of occupier awareness being important in using the dwelling's construction to its full potential and therefore not requiring mechanical intervention.

As mentioned above, windows should be used for natural daylight, but they may be becoming a feature rather than a function, with the use of electric light increasing each year (see Section 2.5.2). Historic Scotland research (Baker, 2008) has shown that the heat loss through windows can be reduced by up to 80% if features such as shutters or blinds are fitted. These are only effective in reducing heat loss if used continuously, which would minimise the natural daylight and encourage increased use of electric lighting. Furthermore, the use of shutters and blinds will reduce the solar gains to the internal fabric and surfaces, and reduce the value of the thermal mass (Holmes & Hacker, 2007). A balance must therefore be found between the benefits of reduced heat loss, an increase in electric lighting and reduced solar gains.

Furthermore, windows still provide their intended use of delivering fresh air to the occupants (Rijal et al., 2008). If the internal temperature or air quality reaches uncomfortable levels, occupants may be more likely to open a window than to turn the heating down, as an open window has an immediate effect, at which point the heating system works harder to heat the incoming cool air. Therefore, better education of occupants may lead to lower internal temperatures, and less wasted heat energy as windows are opened less whilst the heating is on.

Demographics can be important to dwelling energy use as well, through the activities in the dwellings, the hours spent in the dwelling, and when the occupants are present during the day. The ageing population in the UK is leading to an increasing growth in the number of people aged 75 and over, and an increase in the number of single pensioner households; this change will increase the need for winter heating and summer cooling, for health as well as comfort (Roberts, 2008).

### *2.6.3 Occupancy effects*

What follows is a further explanation of points introduced in Section 2.5, regarding the effect that occupancy can play on domestic energy use. A study by Petterson (1994) found that the effect of occupants is more significant than the effect of the climate, and suggests that not knowing the occupant's behaviour can lead to variations of up to 20% between the predicted energy consumption of energy assessment methodologies. Although this study was carried out prior to the introduction of standardised assessment methodology, and was conducted using a building stock dissimilar to the Scottish dwelling types, this author believes the study does show the merit of better understanding the effects of occupancy behaviour towards energy use.

As discussed in Section 2.5.1, the energy consumption associated with space heating in the UK has risen as occupants have wanted higher internal temperatures. There is scope to raise occupant's awareness of their practices with respect to heating, to not only provide a more comfortable living environment, but also to potentially reduce the energy consumption of the dwelling.

Occupants perceive the internal temperature from the air temperature and the temperature of surfaces within the room; if the surfaces of the walls are warmer, the heating set-point can be lower, as the occupants do not feel as cold (Walsh et al., 2006). In dwellings with high thermal mass, the surface temperature of the walls may be higher than in a cavity wall construction as the heat stays in the construction rather than travelling through it, and therefore could potentially have lower set-point temperatures on the heating system, without lowering the thermal comfort of the occupant (Walsh et al., 2006). Furthermore, occupant's behaviour towards use of the heating and window opening can be controlled by the external weather conditions and the perception of the difference between internal and external conditions (Andersen et al., 2009).

A further example of the effects of occupancy can be seen in the different heating needs of different ages. The elderly will typically require longer heating periods than those of working age, as they are typically in the dwelling for longer each day and require higher internal temperatures (Roberts, 2008).

A study looking specifically at traditionally constructed dwellings in Scotland in 2008 included occupancy activity and appliances within profiles to study internal gains (Jenkins, 2008), with the aim of improving energy modelling of this type of construction. By better representing the internal gains within a dwelling with high thermal mass, a better representation of the internal temperature (before heating) can be obtained, and therefore a better representation of the energy used for space heating.

The Government's target to have a smart meter in every home by 2020 will only produce a reduction in energy use if occupants are given the right information at the right time (Fischer, 2008) and consistently, to embed the behaviours associated with lower energy use until they become habits (Darby, 2006). There are some fears that showing occupants their real-time energy usage will actually produce an increase in energy usage, especially in dwellings that previously had low consumption (Fischer, 2008).

An example of a change in behaviour that is better suited to a dwelling with high thermal mass is to run the heating system off a smaller boiler working at maximum output, and therefore efficiency, by utilising a longer period of operation at a lower output (Wheatley, 2008). More research is needed on a case by case basis to determine if this method is more cost effective.

The energy used for cooking accounts for 16% of total domestic energy consumption (DECC, 2012) and is largely dependent on the occupants; the associated carbon emissions are dependent on the fuel source used, predominantly electricity and gas. The energy required will depend on the number, age and lifestyle of people in the dwelling.

Certain lifestyles will lend themselves to different methods of cooking, such as predominantly microwave food or take-away for very busy people, or two cooked meals each evening for those with young children, or a slow cooked very energy intensive meal every evening.

As discussed in Section 2.5.6, appliances and equipment in a dwelling are significant energy consumers. For example, a dwelling with a young family is likely to have far more equipment than a dwelling with just a single occupant. Audio and visual equipment such as televisions and stereos are high users of energy, in addition to computers and associated gaming equipment, as well as beauty and hygiene equipment such as electric razors, hair dryers and hair straighteners.

As Figure 2.9 shows, there has been a steady increase in the number of appliances in UK homes since 1970. This could be in part due to an average increase in disposable income (Church, 2004), coupled with a decrease in average cost of household electrical goods (Boardman et al., 1995). A number of occupancy variables influence the energy use (at a national stock level), which combine to give an overall steady increase in electrical demand for appliances (Environmental Change Institute, 2010). The number of households has increased (UK-wide), and whilst the number of occupants per house has fallen, this has led to a steady increase in the number of appliances. The efficiency of the equipment has improved, but this has not been sufficient enough to offset the increase in number, leaving an overall effect of increased energy consumption and emissions. However, Jenkins (2008) discusses how newer and more efficient appliances (and lighting) are more likely to be accepted by occupants than other high-cost measures. Therefore, purchasing new appliances may be the first step for the public to take in an effort to reduce their energy bills and emissions.

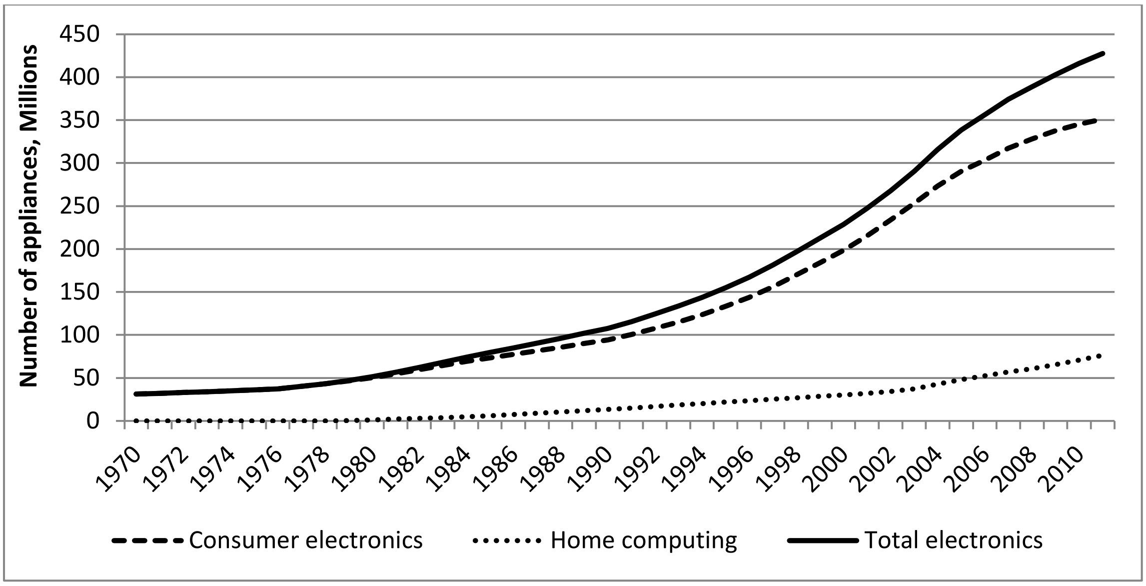


**Figure 2.9 How the number of appliances has changed in the UK since 1970 (DECC, 2012).**

With respect to future energy use, a number of household appliances have reached saturation point, whilst others are set to increase further (Environmental Change Institute, 2010). For example, refrigerators are common in nearly every home and their number will only increase with new homes built, whereas digital or cable TV set top boxes will continue to increase whether new homes are built or not.

## 2.7 Modelling

There are many reasons for energy assessment of buildings, collectively policy-driven and occupant driven: both are discussed in this introduction to energy assessment, before the types of models used are explained, and the input required is examined.

The policy behind energy assessment originates from the European Union, and the Energy Performance of Buildings Directive (EPBD). As explained in Section 2.2, the EPBD (Directive 2002/91/EC) was originally adopted in 2006 and recast in 2009, requiring a common methodology of energy assessment and implementation of energy certification of domestic and non-domestic dwellings across all Member States (MS). In Scotland, the requirement for energy assessments is included with Section 6 – Energy, of the Building Standards.

Each MS has different housing qualities, standards, expectations, and construction methods and materials, therefore while each MS requires energy assessments using a common methodology, there are slight variations in the detail used and calculation of energy assessment in each MS. Research by the European 'Assessment and Improvement of the EPBD Impact' (ASIEPI) project outlines the differences across MS by providing each MS with an identical building to model, then comparing the different outcomes. The project found that some MS use internal dimensions while others use external dimensions; some MS use total floor area, others use dwelling volume; some countries include minimum performance standards within the calculation, others use their Building Standards to control the standards so the values are implied and not calculated; some MS only consider energy used for heating, others include all aspects of energy use; and minimum standards of fabric heat loss differ across all MS; however all MS use the same method for calculating space heating and hot water requirements (Spiekman, 2009). A second project under the ASIEPI project examined the different approaches to thermal bridges across Europe, finding that most MS use a simplified approach, but others such as Finland, Norway and Germany use more detailed approaches (Cittero, 2009). This will be discussed further in the coming sections.

The occupant driven reasons for energy assessment stem primarily from economic motives. As demand for energy grows and natural finite resources are depleted, the cost of finding, producing and distributing energy increases. These greater costs for producers are passed on to the consumers: in the case of electricity between 2003 and 2008 the cost to electricity firms increased by more than the increased cost to consumers (the generating firms increased cost to consumers but not at the same rate they themselves were coping with); but the cost to gas producers increased less than the increased cost to consumers, i.e. gas companies passed on more cost than was being incurred (Consumer Focus, 2010).

Directly linked with the cost of energy is the issue of fuel poverty (defined in Section 2.2.1). As the cost of heating a dwelling rises, the dwelling becomes more likely to become fuel poor, unless the income of the dwelling also rises. The trend of recent increasing fuel costs is creating a need among homeowners and occupants to reduce their energy bills, which at the same time may involve improving the energy efficiency of the dwelling and the appliances within it.

Energy assessment is most useful when needing to truly understand building performance for reducing bills and improving energy efficiency of, or in, the home. The lack of comprehensive understanding of energy demand within a dwelling may be one of the barriers to lowering dwelling energy demand (Lomas et al., 2006). By understanding the dwelling's energy profile the homeowner or specifier can understand in depth the impact of different choices when considering refurbishments, and on a larger scale, energy and emission comparisons between replacing a dwelling and refurbishing it can be made.

This section relies heavily on the technical guides associated with the models mentioned: SAP 2005 (BRE, 2009), SAP 2009 (BRE, 2010), SBEM (BRE, 2008) and the dynamic modelling is based on the system used by one such software, the IES Virtual Environment (IES, 2009). Unless noted, all material that follows draws from these four sources.

### *2.7.1 Domestic models*

The primary purpose of energy assessment in the UK is to produce Energy Performance Certificates (EPCs) for both domestic and non-domestic buildings, at the point of sale or rent. There are two models used across the UK, one for new-build dwellings, one for existing dwellings. These models are the same throughout the UK, with the devolved nations having slightly different graphics on the output pages.

The model used currently in the UK is the Standard Assessment Procedure (SAP). Over the past twenty years SAP and RdSAP (Reduced data SAP) have undergone many changes, the most recent being in December 2012 (BRE, 2012a).

The BRE Domestic Energy Model (BREDEM) is the basis of the calculation methodology behind SAP. Started in the 1980s as a simple single-zone model, it takes an analytical approach to space heating using the balance of loss and gains (see 2.8.10), and an empirical approach to energy consumers such as hot water (section 2.8.5), cooking and appliances (section 2.8.12) and lights (section 2.8.6), using actual consumption data (Anderson et al., 2002). An in-depth history of BREDEM is given in Kelly et al (2012). The following versions of BREDEM are used in the UK and continually updated:

- BREDEM 8: A monthly calculation method, two zone model, original conception 1991.
- BREDEM 9: The framework for SAP, including heating profiles (e.g. weekday/weekend differences in heating pattern), original conception 1993.
- BREDEM 12: An annual calculation method, two zone model, from 1999, used for National Home Energy Ratings (see below).
- BREDEM 2012: The version for SAP in use from 2013.

Much of the evolution of BREDEM has been the direct result of empirical research findings, and because BREDEM remains a compliance tool, it therefore still does not address non-regulated energy use, such as cooking and appliances (Scottish Government, 2009b). After the introduction of the EPBD in 2002, an update to SAP was needed to ensure consistency in energy assessment methods across the EU, but this too enabled the calculation to remain compliance-based.

This time period also opened up the market to multiple software providers and training companies. One such company was the National Energy Foundation (NEF) who established software for not only SAP, but also for their own rating system, the National Home Energy Rating (NHER), explained in Section 2.3. Comparisons have been made between SAP and NHER, as the calculations differ slightly. The NHER includes information on location of the dwelling, whereas SAP is designed to standardise assessment across the whole of the UK and therefore location is not included. The NHER also includes energy and fuel use of cooking equipment while SAP does not. In a cross comparison between SAP, RdSAP, and the NHER, a report by Changeworks found that the NHER rating appeared higher (better) than expected, and that RdSAP underestimated the performance of the building fabric, with too much reliance on default U-values (Barnham et al., 2008). Despite the publication date of that report however, the models used in the study were considerably older (in modelling years), so whilst the conclusions of the report stand it is worth noting that some of the recommendations within the report, specifically the requirement for more detailed models, have already been implemented.

The SAP 2001 model used in the Changeworks report was found to be insufficient for accurate representation of existing buildings, due to the assumptions used within the calculation. When RdSAP was introduced in 2007, it enabled a single model to be used for both new-builds and existing housing, but by providing a database of information to be used in the calculation where an assessor is missing information that is unobtainable as the dwelling is already built (such as wall construction, thickness, U-values). For dwellings built in the 20$^{th}$ century, the system is relatively fair, banding together age ranges of dwellings, for example all housing post-1984 will have the same characteristics. However for dwellings built prior to 1919, as is the focus of this project, there is a single age band, leading to unrepresentative U-values being used in the model, affecting the model result (Barnham et al., 2008).

In April 2010 the Government released SAP 2009 v9.90, to be used from October 2010. This new model updated carbon emission factors, fuel prices, and climate information, and also included space cooling. The biggest difference is that it moved from an annual calculation to a monthly calculation. The model remained steady-state, but there was slightly more detail than in previous versions. In 2012, v9.91 was released for RdSAP. Figure 2.10 shows how the frequency of updates to the model and information used has increased, but also shows that the model used for RdSAP has been consistently behind that of the model for new-builds, until 2012. Since October 2010, new-build dwellings have been required to use SAP 2009, v9.90, while existing buildings have been using RdSAP 2009, v9.91 since April 2012.

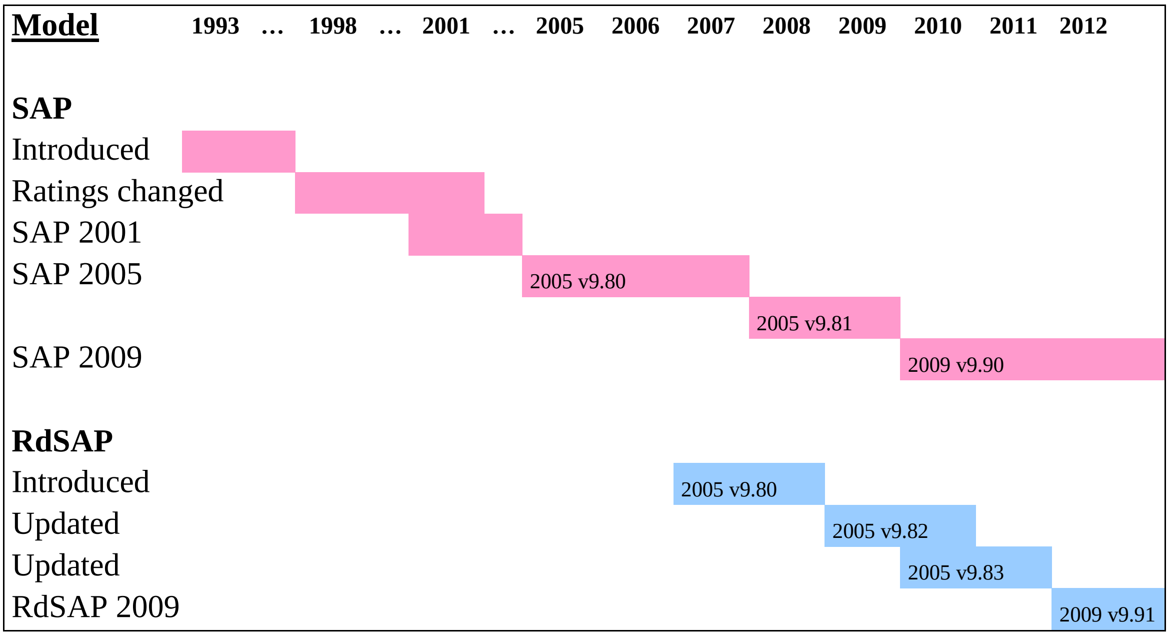


**Figure 2.10 Changes to SAP since its introduction in 1993 (BRE, 2010)**

### *2.7.2 Non-domestic models*

There may be scope for non-domestic models, or their principles and methods, to be included within domestic models, or to replace them. To that end the following section discusses the different levels of non-domestic model used in the UK, and their main differences in input and methodology.

Following the EPBD in 2002, each member state was required to provide details of their National Calculation Method (NCM), which allows a seasonal, monthly or hourly calculation time step. The UK's NCM includes both the monthly SAP and RdSAP methodologies, the monthly Simplified Building Energy Model (SBEM) and the dynamic (hourly) models used for detailed assessment.

The SBEM requires that a building be divided into multiple zones, which are separated by activity type (office, classroom, corridor etc); each zone is then assessed adjacent to the other zones using their own heat gains and losses. While SAP is not location specific, SBEM uses weather data from the Chartered Institute of Building Services Engineers (CIBSE) for 14 locations across the UK, the nearest location being entered into the model (BRE, 2008).

Similar to SAP, as the role of SBEM is to standardise energy assessment across the UK, the energy used for appliances is not included in the assessment as it varies from occupant to occupant.

While SBEM looks at greater spatial detail than SAP, Dynamic Simulation Models (DSMs) look at both high spatial resolution as well as high temporal resolution, to model the changes that occur over time using fundamental mathematics of the heat transfer processes that occur both inside and around a building.

In line with the NCM, dynamic models also require the building to be divided into multiple zones and also use much more detailed CIBSE weather data, for 16 sites across the UK (in Scotland these are Glasgow, Aberdeen, Dundee and Eskdalemuir).

As well as the basic heat gains and losses calculations, DSMs also include convection, heat transfer by air movement, thermal radiation transmitted by surfaces, solar transmission, and absorption and reflection by any glazing. The heat gains utilised are both sensible heat (the temperature change in the air of the room) and latent heat (the change in humidity in the room).

### *2.7.3 Simplicity v complexity*

As outlined earlier, energy assessment is needed to be as accurate as possible for informed decision making, but there are varying levels of complexity of models, and a balance needs to be found between simplicity and complexity. Dynamic simulation methods use detailed input data and take a long time to carry out assessments, whereas simplified steady state methods use a less accurate approach in a faster time. One method of combining accuracy with speed is to use a statistical approach to define polynomial functions from the dynamic model to provide fast statistical methods that in essence are a simplified dynamic approach (Caldera et al., 2008; Jaffal et al., 2009).

Table 2.12 outlines the main differences between the types of model to be looked at within this project.

**Table 2.12 Summary of main variables and differences between assessment methods**

| | SAP | RdSAP | SBEM | Dynamic |
|---|---|---|---|---|
| Accredited for: | New-build Domestic | Existing Domestic | Non-domestic | Non-domestic |
| Construction details | Exact, from plans | Database - unless known | Database - unless known | Database - unless known |
| Thermal Mass | ✓ | ✗ | ✓ | ✓ |
| Include heat gains | ✗ | ✗ | ✓ | ✓ |
| Overheating risk | ✗ | ✗ | ✓ | ✓ |
| Climate variables | Monthly | Monthly | Hourly | Hourly |
| Time to assess | 1-2hrs | 1-2hrs + site visit | 4-5hrs + site visit | 1-2 days + site visit |
| Cost to assess | ££ | ££ | £££ | £££ upwards |

## 2.8 Model input

Dimensions in domestic models use the internal floor areas, as the focus is on heat loss area. This means that the internal partition walls are not included. In non-domestic models such as SBEM the convention is to use dimensions to the centre of the partition wall, see Figure 2.11.

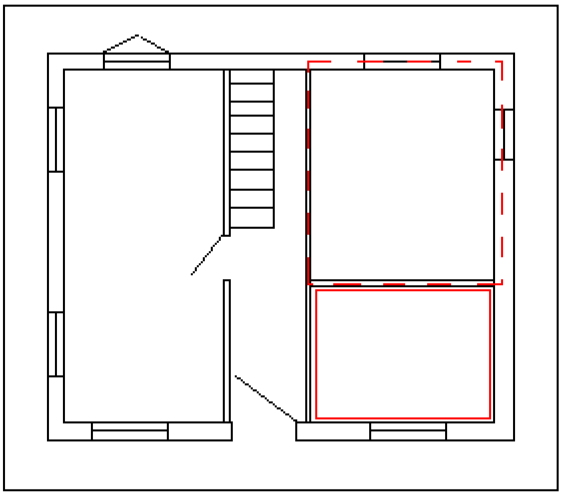

**Figure 2.11 Example dwelling layout with dimension conventions. Solid line = domestic assessment convention, internal dimensions. Dashed line = non-domestic assessment convention, mid-wall dimensions.**

The U-values entered into the calculation are either those calculated using BS EN ISO 6946:2007 "Building components and building elements – Thermal resistance and thermal transmittance – Calculation method", or those in the RdSAP construction database. U-values are required for the floor, walls, roof, doors, windows and roof windows. The calculation does include correction factors if an element is exposed to unheated space (such as a communal stairwell or underground car park), and SAP 2009 now considers the heat transfer between two heated spaces.

As outlined in Section 2.4.2, a U-value is a measure of heat flow through an element, but as the external temperature changes throughout the day, the rate will vary. The National Physical Laboratory is currently researching this variation, to test whether the heat loss in a high thermal mass element is actually less than the U-value suggests (The Concrete Centre, 2009).

The total heat loss through the fabric is calculated as follows:

$$\text{Fabric heat loss (W/K)} = \Sigma(A \times U) + \Psi$$

**Equation 2.1**

Where:

$A$ = Area of each element

$U$ = U-value of corresponding element

$\Psi$ = linear thermal transmittance

### *2.8.1 Thermal bridging*

Thermal bridging is the term used to define the heat transfer between elements at construction junctions (e.g. where an internal partition wall meets the external envelope) and around openings. It gives a numeric value to the way in which heat travels across building fabric.

Each 'route' of heat transfer has a linear transmittance, $\Psi$, the heat flow per degree temperature difference per unit length of the bridge. The thermal bridging ($y$) for the dwelling is the sum of the $\Psi$ value multiplied by the length over which that bridge occurs, divided by the total areas of the exposed external elements.

If no information is available (the case for most existing dwellings) then a default value of $y$ = 0.15 is used. This is approximately twice that which is considered best practice in the UK for new-build housing.

### *2.8.2 Thermal Mass Parameter*

A new variable included in SAP 2009 is the Thermal Mass Parameter, TMP, and is defined by SAP as the heat capacity within the construction, per unit of floor area of the dwelling. The heat capacity, $C_m$ (kJ/m²K), is calculated as the sum of the individual heat capacities of each element (floor, walls, roofs, and internal walls) multiplied by that element's area. The TMP is used when calculating the space heating and cooling loads.

The SAP technical guidelines provide a table of values suitable for use in the SAP calculation for various materials, the values given for external walls is given in Table 2.13. It is seen that the values provided to assessors are not associated with traditional construction of pre-1919 Scottish dwellings. The values given in Table 2.13 are based on the heat capacity of the first 100mm thickness of material, or half the total width of the layer, starting from the inside surface of the layer. Materials beyond (and including) any insulation layer are not included.

**Table 2.13 External wall construction heat capacities, from SAP Table 1e (BRE 2010)**

| **Construction** | **Heat Capacity, $\kappa_i$ kJ/m$^2$K** |
|---|---|
| **External walls – masonry, solid external insulation** | |
| Solid wall: dense plaster, 200mm dense block, insulated externally | 190 |
| Solid wall: plasterboard on dabs or battens, 200mm dense block, insulated externally | 150 |
| Solid wall: dense plaster, 210mm brick, insulated externally | 135 |
| Solid wall: plasterboard on dabs or battens, 210mm brick, insulated cavity | 110 |
| **External walls – masonry, solid internal insulation** | |
| Solid wall: dense plaster, insulation, any outside structure | 17 |
| Solid wall: plasterboard on dabs or battens, insulation, any outside structure | 9 |
| **External walls – cavity masonry, full or partial cavity fill** | |
| Cavity wall: dense plaster, dense block, filled cavity, any outside structure | 190 |
| Cavity wall: dense plaster, AAC block, filled cavity, any outside structure | 70 |
| Cavity wall: plasterboard on dabs or battens, dense block, filled cavity, any outside structure | 150 |
| Cavity wall: plasterboard on dabs or battens, AAC block, filled cavity, any outside structure | 60 |
| **External walls – timber or steel frame** | |
| Timber framed wall, one layer of plasterboard | 9 |
| Timber framed wall, two layers of plasterboard | 18 |
| Steel framed wall, warm frame or hybrid construction | 14 |

### *2.8.3 Ventilation*

A properly ventilated building is one that provides sufficient fresh air for healthy occupants, whilst minimising heat loss. The higher the heat loss through ventilation, the greater the energy demands on the heating system leading to higher bills and greater $CO_2$ emissions. There are two variables that provide a building with air changes: ventilation and infiltration.

The ventilation air change rate describes the rate of air flow between the internal and external environments, and is affected by many variables, such as the number of chimneys, flues, vents and fans.

### *2.8.4 Infiltration*

Infiltration is the measure of air tightness of the dwelling, and assesses the effect of gaps within the construction which may be within the envelope, or more commonly, draughts through poorly fitted or unmaintained openings.

When combining the fabric heat loss (Equation 2.1) and ventilation heat loss, the heat loss coefficient is produced. The heat loss coefficient divided by the total floor area gives the Heat Loss Parameter (HLP, with unit $W/m^2K$). The HLP has the same units as a U-value, and can be thought of as a whole house U-value.

### *2.8.5 Domestic Hot Water*

The energy required for domestic hot water (DHW) is taken from SAP and is a function of the total floor area. The SAP 2009 methodology assumes varying DHW usage each month, and dynamic models use the tables from SAP.

Both SAP and RdSAP calculate the hot water usage, energy content of the water used, and the losses incurred across the storage and distribution system. Similarly to the effect of ventilation losses on the heating system, the higher the losses incurred in the DHW system, the harder the system has to work, increasing energy consumption, bills, and emissions.

### *2.8.6 Internal gains*

Internal gains, sometimes called casual gains, describe the heat emitted by certain energy users within the dwelling, which act to reduce the heating demand (Watts, rather than kilo Watts). The pumps to run the heating and hot water systems, as well as fans, give off heat, which are calculated by simple equations in SAP, dependent on the efficiency of the system.

In SAP 2009 the heat gains from lighting, cooking, appliances, and the gains from the occupants (metabolic gains) are calculated using the standardised number of occupants and total floor area, using slightly different equations for typical gains in existing dwellings and the for ‘reduced gains’ in new-build dwellings.

In addition to the ‘equipment’ gains, both the distribution and storage losses from the DHW system outlined earlier are included. These will be lower the better insulated the pipes and any storage cylinders are.

If low energy lighting is used, the internal gains are reduced, as low energy lighting emits less heat from the bulb than traditional older lighting.

### *2.8.7 Solar gains*

Solar gains also contribute towards lowering the heating demand. There are two main ways solar gains contribute – through heating the air, and through warming internal surfaces such as floors and furniture. The level of contribution that the sun can provide depends heavily on the window – its orientation, specification of glazing, and type of frame, but it also depends on the surfaces it is hitting, as darker smoother surfaces will absorb the incoming radiation to greater effect than lighter rougher surfaces.

The solar flux through a window differs depending on the orientation, and the season. SAP 2009 uses a series of equations enabling the latitude of the site, the horizontal flux, and the vertical flux all to be included in addition to the orientation.

While each window type on each orientation is therefore considered, the windows are not attributed to an individual room in domestic modelling, whereas non-domestic modelling does attribute windows to a particular room, due to the zoning requirements (see below).

In SAP the ratio between total useful gains (casual plus solar) and the heat loss coefficient (Gains Loss Ratio, GLR) is calculated, which is then used to provide a utilisation factor which contributes to the space heating requirement calculations along with the thermal mass parameter. As described in Section 2.7.2, dynamic models assess gains in terms of sensible and latent heat, once again using a little extra detail.

### *2.8.8 Internal temperatures*

To calculate the internal temperatures of a dwelling, the domestic and non-domestic methods differ. The domestic models require the dwelling to be split into two zones: the living room, and the rest of the house. As introduced in Section 2.7.2, dynamic models require numerous zones to be defined, and each has different properties.

In SAP, the living room temperature is taken as 21°C, and the temperature in the rest of the house is dependent on the HLP and the controls on the heating system. However, the temperatures vary month by month.

### *2.8.9 Thermal comfort*

The internal and solar gains in a dwelling contribute towards the thermal comfort of the occupants, as well as the temperature of surfaces, and any draughts. Overheating is directly connected to thermal comfort, and it is the gains just discussed that contribute to overheating.

Only dynamic models can assess thermal comfort as they assess the air movement between zones, and better replicate the internal conditions due to the better spatial resolution given by the numerous zones defined for a DSM.

### *2.8.10 Space Heating*

The space heating requirement in any building is a balance of heat gains and losses. The heat balance of a building can be defined generally as:

$P_{tra} + P_{ven} + P_{dyn} – P_{heat} – P_{gain} = 0$

**Equation 2.2**

Where:

$P_{tra}$ = heat transmission through the envelope

$P_{ven}$ = ventilation heat loss

$P_{dyn}$ = dynamically stored heat

$P_{heat}$ = supplied heat to the heating system

$P_{gain}$ = heat gain from internal and solar radiation (Lundin et al., 2004)

In SAP 2009 the level of gains, the mean internal and external temperatures, the utilisation factor, and the rate of heat loss all differ on a month by month basis, combined to provide a monthly space heating requirement.

### *2.8.11 Meteorology*

Every energy assessment model includes weather data, but how specific and how much data is available depends on the model. For heating requirement calculations, the domestic models use average external temperature for the whole of the UK. For cooling requirement calculations, the UK is split into 21 regions (Scotland is 8 of these). SAP includes wind speed, solar radiation and temperature data.

Again, dynamic modelling differs greatly to that of steady state, as the weather data does not just include the 'basics'. The CIBSE uses historical weather data from the Met Office to produce Test Reference Years for each location (see Section 2.7.3), whereby hourly data over a year for the following variables is available for use in the model:

- Dry bulb temperature
- Wet bulb temperature
- Atmospheric pressure
- Wind speed
- Wind direction
- Cloud cover
- Total irradiation on the horizontal surface
- Diffuse radiation on the horizontal

This allows the model to look at the effects of the weather on energy consumption more precisely.

### *2.8.12 Appliances*

As seen above, the heat gains from appliances and equipment in the dwelling are represented when assessing space heating and cooling requirements. However in domestic models appliances and equipment are not included when calculating the dwelling's energy use, unless the dwelling is being assessed for zero carbon status.

The Code for Sustainable Homes is the UK's green homes standard. There are six levels to the Code, with Level 1 being poor, Level 5 being zero carbon (as per Building Standards), and Level 6 being zero carbon (all $CO_2$ is offset, including that not included in the SAP calculation). The calculation for the electrical use for appliances is a function of total floor area and the standardised number of occupants (DCLG, 2009).

## 2.9 Model output

Each methodology provides the assessor with different types and levels of results, summarised in Table 2.14.

Dynamic simulation can provide a more detailed assessment of a building than all other methods, with results including comfort statistics, hourly room temperatures (air temperature, mean radiant temperature, and dry resultant temperature), humidity, air exchanges, surface temperatures, internal gains, in addition to the standard energy consumption and carbon dioxide emissions. This is due to the more detailed input and the higher temporal resolution used.

**Table 2.14 Summary of output from different assessment methods**

| | SAP | RdSAP | SBEM | Dynamic |
|---|---|---|---|---|
| Electricity consumption | ✓ | ✓ | ✓ | ✓ |
| Fossil fuel consumption | ✓ | ✓ | ✓ | ✓ |
| $CO_2$ emissions | ✓ | ✓ | ✓ | ✓ |
| Asset ratings | ✓ | ✓ | ✓ | ✓ |
| Energy use by end use | ✓ | ✓ | ✓ | ✓ |
| Hourly room temperature | ✗ | ✗ | ✓ | ✓ |
| Casual gains | ✗ | ✗ | ✗ | ✓ |
| Air exchanges | ✗ | ✗ | ✗ | ✓ |
| Comfort statistics | ✗ | ✗ | ✗ | ✓ |

Where an asset rating is required for an EPC, a certain level of accuracy and quality should be expected. The quality assurance aspect is required to ensure the simulation is as close to reality as possible, even though precision will not necessarily lead to an assessment that matches reality (Hand et al., 2008). In Scotland, no such quality checks are required by the Building Standards Directorate (Hughes, 2010). However, EPCs can only be produced by qualified assessors who must belong to an accreditation scheme, and it is the accreditation scheme that controls the quality of the assessments, through continuous assessment via random sampling of EPCs. To understand how the Scottish system may change in the future, the current English system could justifiably be a potential baseline for any new quality assurance measures implemented by the BSD. The English system is set by the Department for Communities & Local Government, and run by the accreditation schemes. It requires that ratings on an EPC are within five points (plus or minus, where a ‘point’ is any change on any variable) of an identical assessment carried out by the accreditation firms’ own staff. For example, if an assessor has seven differences larger than the check, and three lower than the check, while the average is four the assessor would fail as there is an overall move of 10 points (Hughes, 2010).

## 2.10 Filling the literature gap

The use of energy assessment for domestic (or non-domestic) buildings is not new. Yet the pace with which changes are introduced in the Building Standards is such that research using assessment methodologies can become quickly outdated. A number of texts have been cited here that carry out energy assessment either on non-specific dwellings or specifically on traditionally constructed homes, but due to the rapid change in assessment methodologies, and the large number of assessment methodologies available (accredited or non-accredited), no single source comparing the most up-to-date version of the accredited steady-state methodology against an industry leading dynamic simulation tool exists until now.

The research encompassed in this thesis aims to bridge that gap, by providing up to date, relevant information to expand the public knowledge base on both energy assessment and traditionally constructed dwellings in Scotland.

Additionally, by devising a bespoke spreadsheet tool for the energy assessment methodologies, the research will have enhanced features that conventional routes of assessment allow. This will enable analysis of the effects of assumptions that the steady state methodology uses, and this aspect of the research is unique.

Because of the bespoke spreadsheet, climate information as explained in Section 2.8.11 can be explored in greater detail with location-specific climates used. Currently no peer reviewed, published, research exists that analyses the effect of using a UK average climate.

Additionally, the effect of assumptions with respect to living room fractions, heat loss inputs, thermal mass, and room layout (with respect to draught lobbies) can all be analysed beyond that allowed by software designed to carry out the assessment; beyond that researched by others.

# CHAPTER 3 – METHODOLOGY

This chapter introduces and summarises the case studies; describes the methods used to compare energy assessment techniques; the parameters within those techniques and the detail required by each.

## 3.1 Method defined

A number of dwelling case studies reflecting the Scottish traditional housing stock were selected using data from the Scottish House Condition Survey (see Section 2.3.2). These case studies were subjected to three methodologies to assess energy performance of dwellings (see Section 3.3 below). The results from the energy assessments were analysed, comparing key results of predicted energy demand and predicted fuel cost, in addition to more specific analysis including demand for lighting, hot water and space heating, and the sensitivity of the methods to changes in variables such as occupancy, air tightness, thermal mass and building fabric characteristics.

## 3.2 The Case Studies

### *3.2.1 CS1 – Tenement Flat*

**Figure 3.1 CS1 from the east.** Source: Google street view

This tenement flat is a traditionally constructed, first floor in a three storey block, mid-terrace tenement in western Edinburgh, believed to have been constructed in the mid-19th century. The house has a recent Energy Performance Certificate with which comparisons can be made, and monthly energy consumption data has been obtained for

2011. This enabled direct comparison between actual energy usage and predicted energy usage, although caution should be used as actual energy usage is dependent on the occupants.

### *3.2.2 CS2 – Large detached house*

The large detached house is a four-storey, L-plan, former Laird's house in the heart of Edinburgh. Believed to have been constructed in the mid-16$^{th}$ Century and rebuilt significantly after fire in the 17th, the house has had a mixed history. Owned at one point by the Earl of Linlithgow, it has been associated with the Regent Moray prior to his assassination in 1570 (RCAHMS, 2011). It consists of a Laird's house, but has also been used as a house for the gardeners at Holyrood Palace, later lodging for two families, and is now offices for Historic Scotland, following extensive refurbishment.

**Figure 3.2 View of the rear of CS2 from the east** (Source: Victoria Ingram)

### *3.2.3 CS3 and 4 – small detached house*

The Garden Bothy is a simple 19$^{th}$ century house near Cumnock, Ayrshire, with a two-up/two-down layout. It has recently been used by Historic Scotland as a research property, providing extensive knowledge with regard to construction materials. CS3 uses the house as it was prior to the interventions. It is a simple layout, with kitchen and living room downstairs and two bedrooms plus small bathroom upstairs. The house backs onto the walled garden, and as such the rear wall has a brick outer leaf over the stone, so from the inside of the walled garden the wall appears to run past the house. The house pre-interventions was of typical construction, with solid stone walls with a lath and plaster internal finish, a slate roof with no insulation, and a timber floor in the living area and solid concrete floor elsewhere.

CS4 uses the house with the refurbishment interventions. These have included:

- Upgrading and changing the heating system, from coal fires and electric room heaters, to a higher efficiency biomass central heating system. The biomass boiler also provides hot water, with an immersion available to heat the water in the summer.
- Insulating behind the lath and plaster with blown beads upstairs, providing thermal insulation without destroying the character and traditional construction of the walls.
- Lining the kitchen walls with a hemp-lime mixture and the living room with insulated clay boards, providing insulation properties with natural materials to ensure breathability and maintaining construction quality.
- Adding insulation under the timber floor and replacing the concrete floor with a concrete floor on a bed of clay aggregate and bead insulation.
- Replacing the single glazed sash windows with double glazed panes in the original frames, and replacing the single glazed metal roof window with a double glazed metal framed roof window, specially designed as a 'conservation window'. By replacing the glazing rather than the frame, the external appearance of the building stays the same while dramatically improving the thermal efficiency of the windows. This area of the Historic Scotland research connects with the large number of listed properties or those in conservation areas that need improvement but can be restricted by planning regulations.
- The refurbishment work combined has had a large impact on improving the air-tightness of the dwelling, with repaired window frames, a new door, new floors,

and improved internal finishes to the walls. This will not only have improved the requirement for space heating through lower heat losses, but also through improved comfort.

- Adjacent to the house on the eastern gable end, a row of single storey outbuildings have also been refurbished. The section nearest to the house now houses the biomass heating system. As the dwelling is too small to house the boiler and hot water system, there is additional heat loss across the pipework leading from the boiler to the house, although this has been reduced by insulating the pipework.

Using both pre- and post-intervention versions of this dwelling will enable a comparison across assessment methods (as outlined later) with respect to the impact of heat loss and air tightness variability, two key issues in traditional construction.

**Figure 3.3 CS3 and CS4 from the north west, before refurbishment.** Source: Moses Jenkins.

### *3.2.4 CS5 – Semi-detached bungalow*

The semi-detached bungalow was built at the end of the $19^{th}$ century, as housing for farm labourers in a village just west of Edinburgh. Part of a larger development at the time, it is one of only two that have survived, the remainder having been rebuilt after falling into disrepair.

The village is off the mains gas grid, so the cottage is heated using bulk LPG from a tank in the garden. The LPG is delivered automatically when the tank reaches a certain level, but there is no way of knowing the LPG usage until the bills arrive quarterly.

The electricity is on a pre-pay system, the only case study to use this method of electricity payment.

**Figure 3.4 View of CS5 from the south east.** Source: Victoria Ingram

### *3.2.5 Case Study Summary*

The differences between case studies are highlighted in Table 3.1.

**Table 3.1**. **Case study summary.**

| | **Dwelling type** | **Constructed** | **Primary wall construction** | **Total floor area ($m^2$)** |
|---|---|---|---|---|
| CS1 | Tenement flat | Late 19th century | Solid stone, lath and plaster | 65 |
| CS2 | Detached house (large) | Mid 16th century | Stone rubble, lath and plaster | 341 |
| CS3 | Detached house (small) | Mid 19th century | Solid stone, lath and plaster | 63 |
| CS4 | Detached house (small) | Mid 19th century | Solid stone, lath and plaster with energy efficiency interventions | 63 |
| CS5 | Semi-detached bungalow | 1899 | Solid stone, lath and plaster | 48 |

## 3.3 The models

Following the review in Section 2.7, the four energy assessment methodologies used are outlined in Table 3.2.

**Table 3.2 Summary of energy assessment methods used**

| Method | Calculation | Real-world usage | Temporal resolution |
|---|---|---|---|
| SAP 2009 | Steady State | New-build housing EPCs.<br>Prove compliance with Standards/Regulations. | Monthly. |
| RdSAP 2009 | Steady State | EPCs for existing buildings at point of sale/let.<br>Calculations for energy intervention advice. | Monthly. |
| IES<Virtual Environment> | Dynamic Simulation | Typically for non-domestic assessment of energy, environmental impact, comfort, and financial savings. | Input hourly.<br>Output available at 10-minutes. |

Each requires different levels of data input, which differs between steady state and dynamic simulation.

## 3.4 Method Critique

Early work by the International Energy Agency (Lomas, Eppel, et al., 1994) and (Månsson, 1998), investigated optimum methods for validating detailed thermal simulation programs (now referred to as Dynamic Simulation Models, such as IES). Much of this work was carried out in the UK managed by the BRE, utilising their expansive knowledge of SAP. Lomas et al proposed that the only logical route to validate models was to compare the results to measured data, but recognised that this route is also potentially the most problematic. Månsson suggested an additional possible route for validating models is to compare models, rather than models with measured data, which negates any error in the measured data. These two routes are discussed here, as both are present in the project.

### *3.4.1 Empirical validation*

The UK carried out an empirical comparison study reported in (Lomas, Martin, et al. 1994) for the IEA. The comparison study was undertaken in two phases, the first of which was a 'Blind phase' where the assessors used site plans for dimensions, rather than measured dimensions. In the second phase, the assessors were given the measurements as well as possible errors, to provide multiple assessments. The results of the 1994 study concluded that much improvement was required in the models (which it is assumed has been undertaken in the intervening 20years), rather than the assessors.

The blind phase of the 1994 study provided 'added value' as it was more to do with comparison of the model used, rather than an assessors ability with respect to actual measurements and, it can be argued, the intricacies of such models, for example differences in heating regime. It is proposed that while this project uses only simple empirical comparison for one case study of the five, the comparisons of the models by inputting the same data into all methodologies, acts in some respects as the blind phase acted in the 1994 IEA study.

Additonally, the study concluded that calculating a base case, followed by small variations upon this base case, was of value. This project follows that concept, by providing the base case (using all three methodologies), then altering various inputs to calculate the impact of changing inputs on the outputs.

### *3.4.2 Comparison of models*

Many more recent studies follow Månsson's suggestion of comparing methodologies directly with each other. Brun et al. (2009) compared five methodologies, and calculated the differences with regards to both heating in winter and cooling in summer. The study found significant differences between the methodologies, primarily due to the different algorithms used, and also found that each methodology considered the parameters for HVAC slightly differently, i.e. not all were capable of including energy management systems.

Much of the work by Changeworks and Historic Scotland compares tools, and by continuing (and therefore updating) their methods, it is hoped this project's research has greater applicability to the Historic Scotland audience.

By comparing tools that are Government accredited methodologies, this project has the ability to be directly applied to policy, as well as reach a wider audience. Using previous experience gained whilst employed as an energy assessor using SAP it is hoped that 'assessor errors' are reduced, and that a true representation of how an assessor would react to certain building challenges can be achieved.

## 3.5 The input

The detail entered for each model is outlined here, categorised by variable, in order of model simplicity (RdSAP, SAP and IES). Following the method used by Domestic Energy Assessors where construction information is known it is used, and where unknown, default construction inputs are gained from the RdSAP guidance, which supplies inputs dependant largely on age of construction. What follows is a description of the constructions and systems used in each method.

### *3.5.1 Construction – walls*

Each case study has a slightly different external wall finish, suggesting the potential for differing construction within the wall. The oldest property, CS2, has a rubble wall, while the later properties all have an ashlar finish. All case studies have an internal lath and plaster finish except CS4, which has the retrofitted hemp fibre board.

Within the energy assessment, constructions are used primarily for heat loss calculations. The area of wall can be the largest heat loss area, having different impact whether associated with large detached houses (e.g. CS2) or small mid-floor, mid-terrace flats (e.g. CS1).

The wall construction is also used to calculate the Thermal Mass Parameter (TMP). The heat capacity within the construction is multiplied by the area of the wall to gain an overall heat capacity of each section of the construction, and in turn the whole building. Within RdSAP, the depth of the wall is negligible with respect to both U-value (as an assumed value is used) and TMP, as only the first 100mm (from the internal surface) is included. This has implications for CS2, where different depths of wall are present, but are inputted as a single wall type into the RdSAP calculation. The same values are used in the SAP and IES<VE> calculations to allow for consistency in the assessments and ensure the methodology is under scrutiny, rather than the input. However, research carried out for Historic Scotland by Glasgow Caledonian University has measured in-situ U-values at the CS3 dwelling, and identified the differences between measured and calculated U-values. These are displayed in Table 3.3 alongside the values used according to RdSAP.

**Table 3.3 Measured and calculated U-values at CS3**

| Construction | In-situ U-value (Measured)[a] W/m$^2$K | In-situ U-value (Calculated)[a] W/m$^2$K | RdSAP 2009 U-value[b] W/m$^2$K |
|---|---|---|---|
| Kitchen, east wall | 1.3 | 1.2 – 1.6 | 1.5 |
| Kitchen, north wall | 0.9 | 1.2 – 1.6 | 1.5 |
| Kitchen, south wall | 0.9 | 1.2 – 1.6 | 1.5 |
| Living room, west wall | 1.3 | 1.2 – 1.6 | 1.5 |
| Bedroom 1, north wall | 1.1 | 1.2 – 1.6 | 1.5 |
| Bedroom 1, west wall | 1.1 | 1.2 – 1.6 | 1.5 |
| Bedroom 1, south wall | 1.1 | 1.2 – 1.6 | 1.5 |
| Bedroom 2, north wall | 1.3 | 1.2 – 1.6 | 1.5 |
| Bedroom 2, east wall | 1.1 | 1.2 – 1.6 | 1.5 |
| Bedroom 2, south wall | 1.3 | 1.2 – 1.6 | 1.5 |

**Notes**

[a] (Baker, 2011)

[b] Based on age band A, stone wall construction in Table S7 in RdSAP 2009 v9.90, p120 (BRE, 2010).

Energy assessment calculations also allow input for a 'semi-exposed' wall, where the wall has heat loss associated with it, but not to the same extent as an external wall, for example a wall adjacent to an unheated corridor or stairwell, seen in properties such as CS1.

SAP and RdSAP use Equation 3.1 to apply a factor to the equivalent external U-value, to ascertain the semi-exposed U-value.

$$\boldsymbol{U = \frac{1}{\frac{1}{U_0} + R_u}}$$

**Equation 3.1**

Where:

- $U_0$ is the original U-value of that construction if exposed
- $R_u$ is the factor applied to represent the heat loss to an adjacent unheated yet internal space

In the case of CS1, the only case study with a semi-exposed wall to the unheated central stairwell, the resulting U-value is 0.64W/m$^2$K.

A new feature within SAP and RdSAP 2009 is that of party walls, to recognise the transfer of heat between two dwellings, even if the two dwellings are heated to the same temperature. Where the dwellings are separated by a solid wall (as in all case studies in this research where semi-detached), the U-value is 0.00W/m$^2$K. This is because heat transfer between two identically heated dwellings is due to air flow within the construction, and a solid wall should allow little or no air movement, therefore no heat transfer.

The IES model requires the assessor to input construction details, and the software calculates the wall U-value based on thickness, conductivity, density, heat capacity and resistance of each material. For the purposes of this research, these values have been altered to ensure a U-value is used as similar to that used by SAP and RdSAP, whilst keeping the depth of construction as close to the actual depth as possible. This is because whilst in SAP the internal dimensions are used, in IES, the external measurements are used, and inner volumes ‘switched on’ using the depth specified in the construction database.

This strategy ensures comparison is possible between calculation methods using similar information, despite IES being so different to SAP and RdSAP.  This has implications on CS1, where the heat capacity within the wall may be more significant to energy usage than the heat loss U-value as there is no heat loss through the floor, party walls, or roof.

### *3.5.2 Construction – roofs*

Heat loss through the roof is relatively straightforward, as it directly correlates to the type and depth of any insulation.  With the exception of CS1 that has no roof, all case studies here have pitched roofs.  With pitched roofs, insulation may be between joists at ceiling level, or between the rafters either above an empty attic space, or between the rafters where a room in the roof is present.  SAP and RdSAP follow simple procedures to ascertain what U-values should be used and how they should be calculated.  Figure 3.5 shows the method used to establish how the type of roof construction is determined.

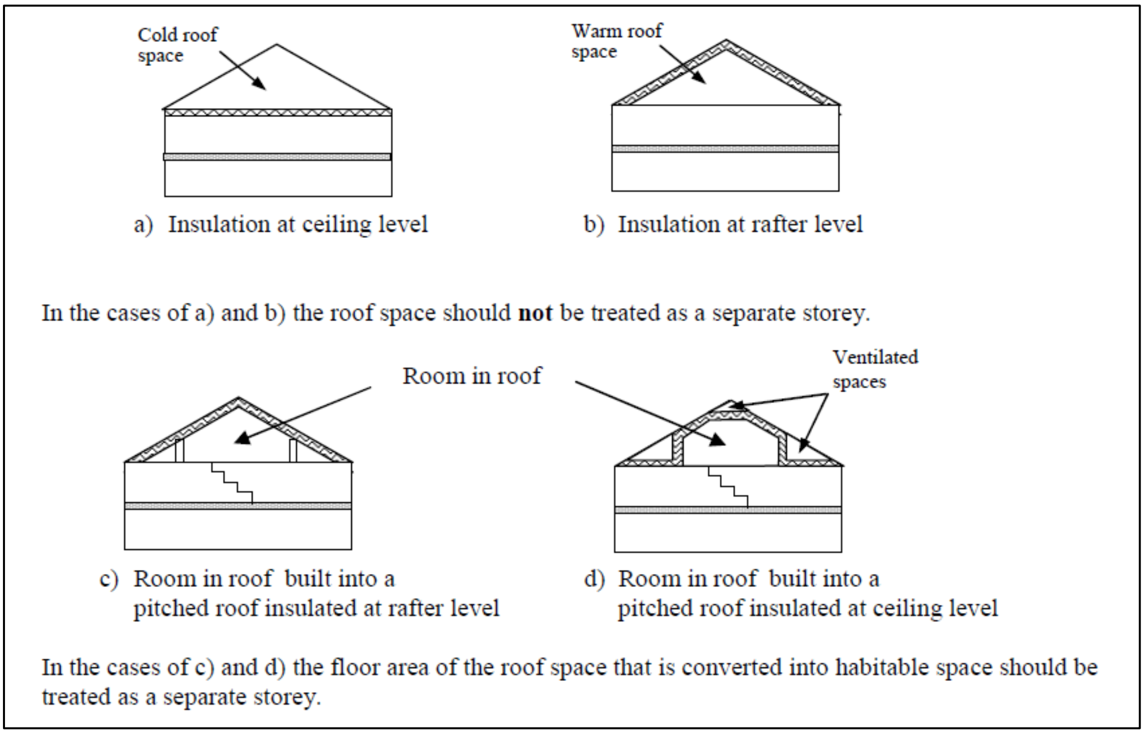


**Figure 3.5 How SAP decides roof type (BRE, 2012a)**

If an assessor has visual proof, or documented evidence with respect to insulation measures, a U-value associated with that level of insulation may be used, either calculated or using an RdSAP default value for that level of insulation. RdSAP can also use the age of the building to determine the level of insulation that can be assumed where unknown, this is shown in Table 3.4. Again, for the purpose of this research, the same U-value for roofs is used across each methodology to ensure the method itself is tested, rather than the input, this value for age band A is shown in *italics*.

Similar to the wall constructions, IES allows the user to enter construction information, and calculates the U-value for the assessor. Again, the U-value in IES has been altered to be as close to the SAP value as possible.

**Table 3.4 U-values for roofs whose insulation is unknown, from Table S10, RdSAP 2009 v9.90 (BRE, 2010)**

| Age band | Assumed Roof U-value ($W/m^2K$) | | | | | |
|---|---|---|---|---|---|---|
| | **Pitched, slates or tiles<br><br>Insulation between joists** | **Pitched, slates or tiles Insulation between rafters** | **Flat roof** | **Slates or tiles Room-in-roof** | **Thatched roof** | **Thatched roof Room-in-roof** |
| *A, B, C, D* | *2.3 (none)* | *2.3 (1)* | *2.3 (1)* | *2.3 (1)* | *0.35* | *0.25* |
| E | 1.5 (12 mm) | 1.5 (1) | 1.5 (1) | 1.5 (1) | 0.35 | 0.25 |
| F | 0.68 (50 mm) | 0.68 (1) | 0.68 (1) | 0.80 (1) | 0.35 | 0.25 |
| G | 0.4 (100 mm) | 0.40 (1) | 0.40 (1) | 0.50 (1) | 0.35 | 0.25 |
| H | 0.29 (150 mm) | 0.35 (1) | 0.35 (1) | 0.35 (1) | 0.35 | 0.25 |
| I | 0.26 (200 mm) | 0.35 | 0.35 | 0.35 | 0.35 | 0.25 |
| J | 0.16 (250 mm) | 0.20 | 0.25 | 0.30 | 0.30 | 0.25 |
| K | 0.16 (250 mm) | 0.20 | 0.25 (2) | 0.25 (2) | 0.25 (2) | 0.25 (2) |

(1) If the roof is known to have more insulation than would normally be expected for the age band, use the lower of the value in the table plus:

50 mm insulation or thickness unknown: 0.68

100 mm insulation: 0.40

>150 mm insulation: 0.30

(2) 0.20 $W/m^2K$ in Scotland, reflective of different backstop U-values as required for new-builds in the Building Standards (Scotland) and Building Regulations (England & Wales)

### 3.5.3 Construction – floors

When using SAP software, the assessor uses a U-value calculator to determine U-values based on the construction specification from the architect. For RdSAP, equations are used to determine U-value, based on whether the floor is suspended or solid. Where floor construction is unknown, RdSAP decides whether the floor is suspended or solid and how much insulation is present depending on the age of the dwelling. For all pre-1919 dwellings, RdSAP assumes a suspended timber floor with no insulation, unless the assessor has proof of a different construction. For this research, that proof is available for CS3 and 4.

The following parameters are used when calculating the U-value of a ground floor in RdSAP:

- Wall area (A)
- Wall perimeter (P)
- Wall thickness (w)
- Soil type thermal conductivity ($\lambda_g$), RdSAP assumes to be clay, $\lambda_g$ = 1.5 W/mK
- $R_{si}$ = 0.17 m$^2$K/W
- $R_{se}$ = 0.04 m$^2$K/W
- Floor construction
- Floor insulation thickness thermal conductivity = 0.035 W/mK

In addition, the thermal resistance ($R_f$) is calculated depending on whether a solid or suspended floor.

- Solid floor: $R_f = 0.001*d_{ins}/0.035$, where $d_{ins}$ is the insulation thickness in mm
- Suspended floor: $R_f$ = 0.2 m$^2$K/W

**Equation 3.2**

When calculating the U-value of a suspended floor, the following parameters are also included:

- Height above external ground level, h = 0.3 m
- Average wind speed at 10m height, v = 5 m/s
- Wind shielding factor, $f_w$ = 0.05

– Ventilation openings per m exposed perimeter, $\varepsilon = 0.003$ m$^2$/m

– U-value of wall to underfloor space, $U_w = 1.5$ W/m$^2$K

The method used to determine the U-value of a solid ground floor is as follows:

1. $d_t = w + \lambda_g \times (R_{si} + R_f + R_{se})$
2. $B = 2 \times A/P$
3. If $d_t < B$, $U = 2 \times \lambda_g \times \ln(\pi \times B/d_t + 1)/(\pi \times B + d_t)$
4. If $d_t > B$, $U = \lambda_g / (0.457 \times B + d_t)$

**Equation 3.3**

The method used to determine the U-value of a suspended ground floor is:

1. $d_g = w + \lambda_g \times (R_{si} + R_{se})$
2. $B = 2 \times A/P$
3. $U_g = 2 \times \lambda_g \times \ln(\pi \times B/d_g + 1) / (\pi \times B + d_g)$
4. $U_x = (2 \times h \times U_w/B) + (1450 \times \varepsilon \times v \times f_w/B)$
5. $U = 1 / (2 \times R_{si} + R_f + 0.2 + 1 / (U_g + U_x))$

**Equation 3.4**

Similar to semi-exposed walls, there are also calculation methods specified for semi-exposed floors (for example above an unheated space such as garages), exposed floors (such as above an open car park) and floors above partially heated space (such as flats above shops, where the shops are occupied when the dwelling is unoccupied). These calculations are not needed for any of the case studies in this research.

For each case study, the ground floor U-values have been calculated using the above method within RdSAP 2009, and then used in SAP 2009 and IES. This is the same strategy as explained in 3.5.1, for parity across models.

IES uses a similar method to calculate the ground floor U-value as used by SAP and RdSAP: calculate a U-value according to the method described in 3.5.1, then apply an adjustment to the U-value depending on the floor area, perimeter, edge insulation, and ground conductivity. This calculation has been forced at use the U-value as given in RdSAP.

Table 3.5 gives an overview of the U-values used in each case study in each model.

**Table 3.5 Construction input summary**

| | U-value ($W/m^2K$) | | |
|---|---|---|---|
| | **SAP 2009** | **RdSAP 2009** | **IES** |
| **CS1** | | | |
| External wall | 1.5 | 1.5 | 1.4 |
| Roof | | N/A | |
| Floor | | N/A | |
| **CS2** | | | |
| External wall | 1.5 | 1.5 | 1.5 |
| Roof | 2.3 | 2.3 | 2.6 |
| Floor | 0.6 | 0.6 | 0.5 |
| **CS3** | | | |
| External wall | 1.3 | 1.5 | 1.4 |
| Roof | 2.3 | 2.3 | 4.0 |
| Floor | 0.8 | 0.8 | 0.7 |
| **CS4**[1] | | | |
| External wall | 0.5 / 0.4 / 0.7 / 0.7 | 0.6 | 0.5 / 0.4 / 0.7 / 0.7 |
| Roof | 0.2 | 0.2 | 0.2 |
| Floor | 0.4 / 0.8 | 0.4 / 0.6 | 0.1 / 0.4 |
| **CS5** | | | |
| External wall | 1.5 | 1.5 | 1.4 |
| Roof | 0.2 | 0.2 | 0.1 |
| Floor | 0.6 | 0.6 | 0.6 |

**Notes**

1. Multiple values are given for CS4 as there are multiple types of wall and floor

### *3.5.4 Thermal bridging*

The thermal bridges that occur at junctions between building fabric elements are calculated using Appendix K within SAP, and Appendix K combined with Table S13 for RdSAP. Appendix K allows two methods for calculating thermal bridging. The more complex method requires the assessor to receive additional training, and involves calculating the linear transmittance of each bridge independently. The simpler method uses a simplified calculation, and this method (Equation 3.5) is used in this research. The term $H_{TB}$, representing the heat transferred through thermal bridging is given by:

$$H_{TB} = y \sum A_{exp}$$

**Equation 3.5**

Where $A_{exp}$ is the total area of external elements, and y = 0.15.

IES allows the user to specify a thermal bridging coefficient to each construction, although a default value of 0.035 W/m$^2$K can be used. This default value represents a typical office construction built to robust details (arguably the predominant commercial application of IES), and is therefore not used in this project. The user can specify that IES should use the default value for the specific construction, and IES will vary the thermal bridging coefficient depending on the construction entered by the user.

### *3.5.5 Infiltration*

The air permeability, or air tightness, of a dwelling is used in energy assessment when determining the heat lost through infiltration. In the case of new-build constructions (for use within SAP), this is simply done by measuring infiltration of the dwelling. For existing dwellings, the infiltration is calculated in RdSAP according to:

– the number of storeys in the dwelling;
– the structural infiltration (dependant on the construction type);
– the floor construction;
– whether a draught lobby is present (for pre-1919 dwellings RdSAP assumes there is no draught lobby); and
– the level of draughtproofing of windows and doors. All single glazing is assumed to not be draughtproofed, unless known by the assessor. Multiple or secondary glazing types are assumed to be draughtproofed.

As the dynamic simulation method uses a room-by-room approach, an ‘Infiltration profile’ is applied to each zone. For this project, average infiltration rates from the CIBSE Guide A have been used (CIBSE, 2006), which depend on the dwellings type as summarised in Table 3.6.

**Table 3.6 Infiltration rates used in IES for each case study**

| Case Study | Dwelling type | Infiltration Rate ($h^{-1}$) |
|---|---|---|
| CS1 | Apartment, storey 1-5 | 1.40 |
| CS2 | 2 storeys | 1.00 |
| CS3 | 2 storeys | 1.00 |
| CS4 | 2 storeys | 1.00 |
| CS5 | 1 storey | 1.15 |

### *3.5.6 Ventilation*

The ventilation rate for a dwelling represents the air changes between the inside and outside of a dwelling, incorporating both infiltration and any purposeful ventilation systems. The SAP takes the infiltration discussed in 3.5.5, adjusts the value to allow for shelter and wind speed, then applies a further adjustment dependent on whether any mechanical ventilation systems are in place or if the property relies on natural ventilation (for example, natural air leakage, trickle vents in window frames, or open windows).

Once again, RdSAP uses the same calculation, but makes assumptions towards calculating the infiltration, assumes the level of shelter, and defaults to the natural ventilation method.

Similar to the infiltration, the dynamic model uses a ventilation profile for each room. This allows the software to include a specific profile for a cookerhood or bathroom extract fan for example, or apply a mechanical ventilation system.

### *3.5.7 Thermal Mass Parameter*

In SAP 2009, the Thermal Mass Parameter (TMP) is used in calculating the internal temperature, towards calculating space heating demand. The TMP is calculated from the heat capacity of the construction. The heat capacity, κ, of each construction element is gained from Table 1e within SAP (Table 2.13 above), however as seen above this table is limited with respect to solid stone walls, as it either assumes solid brick, or any outside structure that has been insulated, neither of which apply to the case studies used here. For that reason, the CIBSE Guide A "Environmental Design" was used, which contains a more complete reference list of material heat capacities.

The method used in SAP is shown in Equation 3.6:

$$TMP = \frac{\sum_{i=1}^{n} \kappa_i \times A_i}{TFA}$$

**Equation 3.6**

Where

- $\kappa_i$ is the heat capacity of a material *i* over area, $A_i$
- TFA is the Total Floor Area of the dwelling, over all storeys

The SAP also provides indicative values of what are considered to be low (TMP = 100 kJ/m$^2$K), medium (TMP = 250 kJ/m$^2$K) and high (TMP = 450 kJ/m$^2$K) mass dwellings.

The RdSAP uses the TMP in the same way, but uses an assumed TMP of 250 kJ/m$^2$K, the equivalent of a medium-mass dwelling in SAP.

The dynamic simulation includes boundary conditions including party walls, but while the calculation considers a heated adjoining space as a boundary condition, the thermal mass within the party wall is included while the average heat loss over time through the construction tends to zero. In SAP, solid party walls are also treated to have zero heat loss to adjoining heated spaces, but heat loss from other construction types of party wall are included.

In the dynamic simulation, thermal mass is considered at the point of entering the construction details. Rather than defining the heat capacity (referred to in SAP as κ), IES considers the specific heat capacity, $c_m$, of each construction across the user-defined area of the construction. To therefore investigate the thermal mass as utilised in IES, each case study's thermal mass parameter was calculated by hand outside the software, using Equation 3.7.

$$TMP = \frac{\sum(A_i \times c_{mi})}{TFA}$$

**Equation 3.7**

Where

- $A_i$ is the area of a construction
- $c_{mi}$ is the heat capacity of a construction
- TFA is the Total Floor Area of the dwelling, over all storeys

### *3.5.8 Occupancy*

A large number of variables within SAP are calculated based on the assumed occupancy of the dwelling. This is one of the areas where SAP's original intended use is still prevalent, as it is the primary way in which SAP can standardise energy requirement across identical dwellings. The following sections on calculation input describe the ways in which occupancy is used towards energy requirement calculations. The assumed number of occupants, *N*, is based on the total floor area, TFA:

$$N = 1 + 1.76 \times [1 - \exp(-0.000349 \times (TFA - 13.9)^2)] + 0.0013 \times (TFA - 13.9) \qquad if\ TFA > 13.9m^2$$

$$N = 1 \qquad if\ TFA < 13.9m^2$$

**Equation 3.8**

Within IES, the occupancy is also used to determine metabolic gains, but can be specified in one of two ways. Firstly, the user can specify a *number of people* per room, and a profile can be set up that allows the user to state the flow of people in and out of rooms and the dwelling. Secondly, the user can specify a value of gains from people per room, again with an occupancy profile across each day.

### *3.5.9 Water heating*

The SAP and RdSAP 2009 method of calculating domestic hot water (DHW) demand is based on the number of occupants and in line with the monthly methodology calculates the energy content of the water from the daily hot water usage, then applies a monthly factor, which allows for variation in hot water usage across the seasons, with 10% more than average used in winter, and 10% less used in summer. This could be due to changes in the pattern of occupants across the seasons, as the lower temperature of the water entering the system during the winter months is taken into account in Equation 3.11. The method is as follows:

1. Calculate average hot water usage (litres/day):

   $$V_{d,average} = (25 \times N) + 36$$

**Equation 3.9**

2. Calculate average daily volume, $V_{d,m}$ (litres/day):

   $$V_{d,m} = V_{d,average} \times monthly\ factor$$

**Equation 3.10**

3. Calculate energy content of water used (kWh/month):

   $$Energy\ content = 4.190\ \times\ V_{d,m} \times n_m \times \frac{\Delta T_m}{3600}$$

**Equation 3.11**

Where:

- $N$ is the number of occupants;
- 4.190 represents the specific heat capacity of water (the energy required to raise the temperature of water by 1°C);
- $n_m$ is the number of days in each month; and
- $\Delta T_m$ is the temperature difference from supply to point of use of hot water drawn off the system in each month.

Energy assessments calculate hot water requirement for two reasons. Firstly, to calculate the fuel required to provide the dwelling with hot water (the energy content as above). Secondly, to calculate the losses associated with the hot water system which contribute to internal gains and therefore indirectly reduce the space heating requirement.

Losses associated with hot water come primarily from the distribution losses as the hot water is transported around the dwelling. In all editions of SAP these losses are assumed to be 15% of the total energy content. There are also losses associated with hot water storage, with losses from water cylinders depending on the volume of water stored, the type and depth of any insulation, and the systems used with the cylinder (for example, cylinder thermostats or timers). It is these losses that are taken into consideration when calculating internal gains towards the space heating requirement.

In the dynamic model, hot water is calculated in a very similar way to SAP as it is based on room occupancy, and for storage losses actually refers to the tables within SAP 2005 for reference values. SAP 2005 is the calculation methodology used prior to the 2009 release; there is no difference between SAP 2005 and SAP 2009 for storage losses.

Whereas SAP asks the assessor whether the primary pipework (that between the boiler and any water storage) is insulated, IES asks the user solely for the *delivery efficiency* – the efficiency of transporting hot water from the boiler around the dwelling. For this research, a delivery efficiency of 85% is used across methodologies, to align with the assumption within SAP of 85% delivery efficiency.

As seen in Equation 3.11, SAP and RdSAP consider the variation in temperature across the year of the inlet water, with $\Delta T_m$ given in the Technical Guide. In IES, the inlet and distributed water temperatures can be specified, and are typically 10°C incoming water, and 60°C output. Heating hot water to 60°C, and storing it at no less than 55°C is required by Building Standards Section 4 "Safety" to reduce the risk of Legionnaires disease, as water above 55°C has a bactericidal effect on Legionella. However, temperature at the tap should be no more than 48°C to prevent scalds, so IES calculating the temperature difference between input and output is considering the most onerous temperature difference.

If the system used to heat DHW is solely used for DHW, the efficiency the methodology uses is that of that particular system, either from SEDBUK or the SAP data tables. If the system used is the same as that for the space heating, the efficiency for the water heating considers both the SEDBUK-specified winter and summer seasonal efficiencies (Equation 3.12).

$$\eta_{water} = \frac{Q_{space} + Q_{water}}{\frac{Q_{space}}{\eta_{winter}} + \frac{Q_{water}}{\eta_{summer}}}$$

**Equation 3.12**

Where:

- $\eta_{water}$ is the efficiency of the DHW system used to calculate fuel demand (%)
- $\eta_{winter}$ is the winter seasonal efficiency (%)
- $\eta_{summer}$ is the summer seasonal efficiency (%)
- $Q_{space}$ is the space heating demand (kWh/month)
- $Q_{water}$ is the hot water demand (kWh/month)

Table 3.7 summarises the detail used in the energy assessment for each case study with respect to the DHW system.

**Table 3.7 DHW systems used in each case study with key information**

| | DHW system | Efficiency[a] | Storage[b] | Keep-hot facility? | Insulated primary pipework[c] |
|---|---|---|---|---|---|
| CS1 | Gas boiler | 88.9 | N | N | - |
| CS2 | Gas boiler | 72 | N | N | - |
| CS3 | Coal-fired back boiler | 32 | Y | - | Y |
| CS4 | Biomass boiler | 65 | Y | - | N |
| CS5 | LPG boiler | 81.4 | N | Y | - |

**Notes:**
[a] The annual average efficiency as calculated in RdSAP 2009 using Equation 3.12
[b] This denotes a separate hot water cylinder, and does not refer to any small internal storage with the boiler
[c] The primary pipework is that which connects the boiler with the storage.

### *3.5.10 Lighting energy use*

In SAP and RdSAP, the lighting energy use is calculated using the following set of equations taken from SAP's Appendix L.

1. Average annual energy consumption for lighting with no low-energy lighting, $E_B$:

$$E_B = 59.73 \times (TFA \times N)^{0.4714}$$

**Equation 3.13**

Where:

- TFA is the Total Floor Area, $m^2$; and
- N is the number of occupants as calculated by SAP

2. The correction factor for low-energy lighting outlets, $C_1$:

$$C_1 = 1 - 0.50 \times L_{LE}/L$$

**Equation 3.14**

Where:

- $L_{LE}$ is the number of fixed low-energy lighting outlets; and
- L is the total number of fixed lighting outlets

3. The correction factor for daylighting depending on the ratio of glass area to floor area, glass transmittance and light access factors (a secondary term, $G_L$), $C_2$:

$$C_2 = 52.2 \times {G_L}^2 - 9.94 \times G_L + 1.433 \qquad \text{if } G_L \leq 0.095$$

$$\boldsymbol{C_2 = 0.096} \qquad \text{if GL} > 0.095$$

**Equation 3.15**

4. The initial value of the annual lighting energy is $E_L$:

$$E_L = E_B \times C_1 \times C_2$$

**Equation 3.16**

5. A cosine function is then applied to this annual figure for lighting energy to take account of seasonal variation. Lighting energy use in month m (January = 1 to December = 12), $E_{L,m}$:

$$E_{L,m} = E_L \times [1 + 0.5 \times \cos\left(2\pi \frac{m - 0.2}{12}\right] \times \frac{n_m}{365}$$

**Equation 3.17**

Where:

- $n_m$ is the number of days in each month, m.

The dynamic model uses the NCM calculation methodology to provide an estimate of the electricity required for lighting, which takes into consideration the activities assigned to a space, the lighting power density (provided by the assessor), and any lighting controls such as dimming or motion sensors (IES, 2012).

The level of low energy lighting used in CS1, CS4 and CS5 is input at 100% low energy lighting, while CS2 and CS3 have 0% low energy lighting.

### *3.5.11 Internal gains*

Internal gains comprise the variables that combine to reduce space heating demand: lighting, appliances, distribution losses from the hot water system, cooking and metabolic gains; in addition to the losses associated with the incoming cold water and evaporation (Table 3.8).

**Table 3.8 SAP 2009 internal gain calculations**

| **Source** | **Calculation** |
|---|---|
| Metabolic | $60 \times N$ |
| Lighting | *Monthly lighting energy use* $\times 0.85 \times 1000 / (24 \times n_m)$ [a] |
| Appliances | *Monthly appliance energy use* $\times 1000 / (24 \times n_m)$ |
| Cooking | $35 + 7 \times N$ |
| Water Heating | *Monthly gains from water heating* $\times 1000 / (24 \times n_m)$ |
| Losses | $-40 \times N$ |

**Notes:**

[a] The lighting energy use is calculated elsewhere, the 0.85 is used as SAP assumes 15% of lighting is external lighting and will not contribute to internal gains

The dynamic simulation includes additional detail and types of gains (Fluorescent Lighting, Tungsten Lighting, Machinery, Miscellaneous, Cooking, Computers and People) and again applies variation profiles specified by the user to calculate the level of internal gains across the day, week and year.

### *3.5.12 Internal temperature*

Both SAP and RdSAP calculate the mean monthly internal temperature, using the same variables. The methodology splits the dwelling into two zones that are heated to different temperatures: the living area (typically the living room), and the rest of the house. The internal temperature is calculated for each zone using the temperature it should reach and the temperature it would fall towards without heating. This second temperature is based on the internal gains, the type of heating system, the external temperature and the thermal characteristics (TMP, heat loss coefficient) of the building fabric are also included. Table 3.9 is taken from Table 9 within SAP 2009 (BRE, 2010) and indicates the standardised internal temperatures and heating regime.

**Table 3.9 Heating periods and heating temperatures, Table 9 from SAP 2009 (BRE, 2010, p193)**

| Living area | | Elsewhere | | |
|---|---|---|---|---|
| **Temperature $T_{h1}$(°C)** | **Hours of heating off $t_{off}$** | **Heating control** | **Temperature $T_{h2}$(°C)** | **Hours of heating off $t_{off}$** |
| 21 | Weekday: 7 and 8 [a]<br>Weekend: 0 and 8 [b] | 1 | 21 – 0.5 HLP | Weekday: 7 and 8 [a]<br>Weekend: 0 and 8 [b] |
| | | 2 | 21 – HLP + 0.085 HLP$^2$ | Weekday: 7 and 8 [a]<br>Weekend: 0 and 8 [b] |
| | | 3 | 21 – HLP + 0.085 HLP$^2$ | All days: 9 and 8 [c] |

[a] Heating 0700-0900 and 1600-2300
[b] Heating 0700-2300
[c] Heating 0700-0900 and 1800-2300

For continued parity across assessments these heating regimes are also used in IES, where the method to calculate internal temperature is the same as in SAP and RdSAP.

### *3.5.13 Space heating*

Once the space heating *demand* is calculated, the assessor then provides information regarding the heating system being used, such as the efficiency and fuel type, which is used to determine the fuel *requirement* to heat the dwelling to the specified temperatures.

The SAP guidelines provide the assessor with the rules to follow to allocate a particular system to primary or secondary heating status, and it also provides the assessor with the fraction of heat to be supplied by the secondary system dependant on the primary system, and whether a system should be identified as a second primary system, or a secondary system. In the case of CS2, which is heated by two identical boilers, these boilers are included as two main systems, each providing 50% of the demand. There appears to be conflicting advice between the SAP guidelines and RdSAP guidelines for Case Study 3, which had coal fires downstairs and electric fires upstairs. This will be discussed further in Section 4.3.1, the data used is shown below in Table 3.11.

In IES, the user selects a heating profile for each zone, and a temperature below which the heating turns on, set at 18°C for each room except the living room, which is set at 21°C as per the calculation in SAP and RdSAP, outlined in Table 3.9.

The heating system information entered into each energy assessment methodology comes from the SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) database. In all methodologies, a winter seasonal efficiency taken from the SEDBUK is used for the heating calculations.

### *3.5.14 Habitable rooms*

RdSAP requires the user to enter the number of rooms, to calculate the fraction of floor area of the living area in comparison to the rest of the house, unlike in SAP, which allows the assessor to enter the exact floor area of the living area. The room count only includes ‘habitable rooms’, defined as:

> “…any living room, sitting room, dining room, bedroom, study and similar; and also a non-separated conservatory…Excluded from the room count are any room used solely as a kitchen, utility room, bathroom, cloakroom, en-suite accommodation and similar; any hallway, stairs or landing; and also any room not having a window.”

(BRE, 2010)

The living area fraction is then taken from Table S16 in RdSAP, Table 3.10 here:

**Table 3.10 Living area fraction used dependent on 'habitable room' count**

| **Number of rooms** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **Living area fraction** | 0.75 | 0.50 | 0.30 | 0.25 | 0.21 | 0.18 | 0.16 | 0.14 |
| | | | | | | | | |
| **Number of rooms** | **9** | **10** | **11** | **12** | **13** | **14** | **15+** | |
| **Living area fraction** | 0.13 | 0.12 | 0.11 | 0.10 | 0.10 | 0.09 | 0.09 | |

The significance of these assumptions on the different case studies will be discussed further in Chapter 4.

### *3.5.15 Input data summary*

Table 3.11 provides an overview of the key information used for each case study with respect to space heating. Table 3.12 summarises the main differences in construction and other key input variables used in the assessments.

**Table 3.11 Summary of heating system inputs**

| | % | System | Fuel | Efficiency SAP 2009 | Efficiency RdSAP 2009 | Efficiency IES |
|---|---|---|---|---|---|---|
| **CS1** | | | | | | |
| Primary 1 | 90 | Vaillant ecoTEC pro24 | Mains gas | 88.9 | 88.9 | 88.9 |
| Secondary | 10 | Electric fire | Electricity | 100 | 100 | 100 |
| **CS2** | | | | | | |
| Primary 1 | 45 | Ideal Concord CX40 | Mains gas | 72 | 72 | 72 |
| Primary 2 | 45 | Ideal Concord CX40 | Mains gas | 72 | 72 | 72 |
| Secondary | 10 | Open fire | Smokeless wood | 32 | 32 | 32 |
| **CS3** ***(according to SAP 2009 & IES)*** | | | | | | |
| Primary 1 | 80 | Room heater | Electricity | 100 | | 100 |
| Secondary | 20 | Open fire with back boiler | Coal | 32 | | 32 |
| **CS3** ***(according to RdSAP 2009)*** | | | | | | |
| Primary 1 | 90 | Open fire with back boiler | Coal | | 32 | |
| Secondary | 10 | Panel heater | Electricity | | 100 | |
| **CS4** | | | | | | |
| Primary 1 | 90 | Biomass burner | Wood pellets | 65 | 65 | 65 |
| Secondary | 10 | Room heaters | Electricity | 100 | 100 | 100 |
| **CS5** | | | | | | |
| Primary 1 | 90 | Vaillant Turbomax Plus 824E | LPG (bulk) | 81.4 | 81.4 | 81.4 |
| Secondary | 10 | Room heater | Electricity | 100 | 100 | 100 |

**Table 3.12 Summary of input variables**

| Case Study | Variable | | | | | |
|---|---|---|---|---|---|---|
| | **External wall finish** | **Internal wall finish** | **Roof construction** | **Floor construction** | **Window type** | **Draughtproofing** |
| 1 | Rough ashlar stone bricks & mortar | Lath and plaster | N/A | N/A | Single glazed sash and case | 100% |
| 2 | Rubble and mortar | Lath and plaster | Slate tiles, rooms in the roof<br>No insulation | Suspended timber | Single glazed sash and case | 0% |
| 3 | Rough ashlar stone bricks and mortar | Lath and plaster | Slate tiles, empty attic space<br>No insulation | Part suspended timber, part solid concrete | Single glazed sash and case | 0% |
| 4 | Rough ashlar stone bricks and mortar | Hemp fibre board, wood/wool-mix insulation | Slate tiles, empty attic<br>250mm lamb's wool | Highly insulated lime concrete | Double glazed sash and case | 100% |
| 5 | Rough ashlar stone bricks & mortar | Plasterboard | Slate tiles, empty attic<br>240mm mineral wool | Suspended timber | Double glazed sash and case | 80% |

## 3.6 Meteorology

Every energy assessment model includes weather data, but how specific and how much data is used depends on the model. What follows is a description of the weather data used by each energy assessment method, ending with a summary table of data specific to the case studies.

### *3.6.1 Monthly data (SAP and RdSAP 2009)*

The 2009 update to SAP and RdSAP (v9.90) increased the detail of the calculation to monthly (from annual), and also increased the use of weather data. Table 3.13 outlines the use of monthly data within v9.90, and the areas of the calculation they are used in.

**Table 3.13 Monthly variables used in SAP & RdSAP 2009**

| Variable (monthly average) | Primary calculation purpose | Towards calculating… | Location |
|---|---|---|---|
| Global solar irradiance | Solar gain | Heating requirement | Latitude 53.4°N |
| Solar declination | Solar gain | Heating requirement | Latitude 53.4°N |
| Wind speed | Infiltration rate | Heating requirement | UK average |
| External temperature | Heat loss rate | Heating requirement | UK average |
| Global solar irradiance | Solar gain | Cooling requirement | Regional |
| External temperature | Heat loss rate | Cooling requirement | Regional |

The addition to v9.90 of calculating cooling requirement is in response to the increasing need of cooling and mechanical ventilation in homes, together with increasing external temperatures (UK Climate Projections, 2012a; UK Climate Projections, 2012b). The cooling requirement is calculated using regional weather data, the regions defined as set out in Figure 3.6. The regional data is available for the three months that SAP defines as requiring cooling: June, July and August. These months correspond to the Met Office definition of summer months (Lewis, 1991).

All case studies use weather data for eastern Scotland – region 14, except CS3 and 4 which use western Scotland – region 15 (see Figure 3.6). The values used by SAP and RdSAP are given in Table 3.14, taken from Tables 6a, 7, 8 (heating requirement figures) and Table 10 (cooling requirement figures) from SAP 2009 (BRE, 2010).

The UK average external temperature and wind speed data is based on data from the Met Office, using climatologically average values for the UK from 1986-2006 (Anderson, 2010), for a location in the centre of the UK (Region 11), rather than an average using all weather stations across the UK. The solar data is based on data published in 1986 by Page & Lebens (Page & Lebens, 1986; Henderson, 2012).


**Figure 3.6 Climate regions used by SAP 2009. Reproduced with kind permission from Brian Anderson, BRE**

### 3.6.2 Hourly data (Dynamic modelling)

Dynamic modelling differs greatly from steady state, as a greater variety of weather data is used at a far higher resolution, using hourly data in weather files produced by the CIBSE. The CIBSE uses historical weather data from the Met Office to produce Test Reference Years for 16 sites across the UK; in Scotland these are Glasgow, Aberdeen, Dundee (CS1, 2 and 5) and Eskdalemuir (CS3 and 4) where hourly data over a year is available for use in the model on the following variables:

- Dry bulb temperature
- Wet bulb temperature
- Atmospheric pressure
- Wind speed
- Wind direction
- Cloud cover
- Total irradiation on the horizontal surface
- Diffuse radiation on the horizontal

This allows the model to look at the effects of the weather on energy consumption in greater detail, allowing the diurnal temperature cycle to be included, as well as seasonal differences. The variables listed above impact upon the calculation of space heating requirement by including detailed external temperature data, the effect of the wind on air and heat movement through the dwelling, and the solar gain through the windows. Due to the large volume of data in a Test Reference Year, the data is not included here.

**Table 3.14 Weather data used with v9.90 of SAP and RdSAP 2009**

| | HEATING REQUIREMENT CALCULATIONS – UK AVERAGE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
| Solar irradiance | 26 | 54 | 94 | 150 | 190 | 201 | 194 | 164 | 116 | 68 | 33 | 21 |
| Solar declination | -20.7 | -12.8 | -1.8 | 9.8 | 18.8 | 23.1 | 21.2 | 13.7 | 2.9 | -8.7 | -18.4 | -23.0 |
| Wind speed (m/s) | 5.4 | 5.1 | 5.1 | 4.5 | 4.1 | 3.9 | 3.7 | 3.7 | 4.2 | 4.5 | 4.8 | 5.1 |
| External temperature (°C) | 4.5 | 5.0 | 6.8 | 8.7 | 11.7 | 14.6 | 16.9 | 16.9 | 14.3 | 10.8 | 7.0 | 4.9 |
| **COOLING REQUIREMENT CALCULATIONS – EASTERN SCOTLAND (CS1, 2 & 5)** | | | | | | | | | | | | |
| | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
| Solar irradiance (W/m$^2$) | | | | | | 187 | 177 | 146 | | | | |
| External temperature (°C) | | | | | | 13.2 | 15.2 | 15.0 | | | | |
| **COOLING REQUIREMENT CALCULATIONS – WESTERN SCOTLAND (CS3 & 4)** | | | | | | | | | | | | |
| | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
| Solar irradiance (W/m$^2$) | | | | | | 186 | 183 | 154 | | | | |
| External temperature (°C) | | | | | | 13.1 | 14.9 | 14.8 | | | | |

## 3.7 Summary

Five case study dwellings built with solid stone walls have been assimilated in three energy assessment methodologies, both simple and complex. The differences in output will be analysed to ascertain the ability of the different methodologies to model real-world energy use, and investigate the finer detail within the models, such as the inclusion of thermal mass. There are two key routes of analysis: by case study, and by model.

What directly follows in Chapter 4 is the results for each case study, focused on a particular characteristic relevant to that dwelling type, for example the effect of draught lobbies, lighting, heating zones and heating system efficiency. Chapter 5 will combine the key results from across the case studies, and will provide the findings as to whether monthly calculations within SAP are representative; how the assumptions used in RdSAP affect the end results of an assessment; and how a dynamic assessment differs to steady state. There will also be an exploration of the key findings from the case study summaries, to highlight any trends, similarities or conflicting results.

# CHAPTER 4 – CASE STUDY ANALYSIS

This chapter describes the main features of the case studies and their analysis. Each case study brings a unique aspect to the research and it is these particular aspects that will be studied in greatest detail in the following subchapters. The first two case studies explore fabric heat loss, with CS1 providing an analysis comparing predicted energy use with measured energy use, and CS2 analysing the effect of assumed occupancy and living room area in larger dwellings. As they use the same dwelling albeit with differing constructions, CS3 and 4 examine the differences that small changes to the dwelling can make to the resulting predicted energy usage. The smallest dwelling, CS5, considers the effect of having large areas of heat loss in comparison to the floor area.

An overall view of the models and how they represent the case studies is provided separately in Chapter 5.

## 4.1 Case Study 1 – Tenement flat

### *4.1.1 Fabric heat loss*

The tenement flat firstly has the ability to challenge the SAP methodology to calculate fabric heat loss, as there is comparatively little heat loss area in a mid-terrace and mid-floor dwelling: only the front and back walls have evaluated heat losses as all other areas have heated adjacent spaces. Secondly, metered gas and electricity data is available for a 12 month period via the owner's readings and data collection, with an online detailed account history available from British Gas. This allows an invaluable insight into how representative the methods are with respect to energy use.

The fabric heat loss is calculated using Equation 4.1: a summation of the areas of each building element and their associated U-values:

$$Fabric\ heat\ loss = \sum_{i=1}^{n}(A_i \times U_i)$$

**Equation 4.1**

Where:

$A_i$ is the area of each element *i*; and

$U_i$ is the U-value of each element *i*.

As Table 4.1 shows, the fabric heat loss value differs slightly across the domestic models, and is slightly higher in IES. The values in SAP 2009 and RdSAP 2009 for both fabric heat loss and $c_m$ are similar, with the small difference due to the assumptions that RdSAP makes towards the area of openings.

**Table 4.1 Fabric heat loss values for CS1**

| Parameter | Calculation | Value | | | |
|---|---|---|---|---|---|
| | | SAP 2009 | RdSAP 2009 | IES | |
| **Fabric heat loss** | $\sum(A \times U)$ | 90.21 | 96.72 | *115.94* | W/K |
| **Heat capacity, $c_m$** | $\sum(A \times \kappa)$ | 7929 | 7866 | *29,115* | kJ/K |
| **Thermal Mass Parameter** | $c_m \div TFA$ | 121.16 | 120.20 | *515.95* | kJ/m$^2$K |
| **Thermal bridges** | $0.15 \times \sum A$ | 7.89 | 7.90 | *7.99* | W/K |
| **Total fabric heat loss** | $\sum(A \times U) + (0.15 \times \sum A)$ | 98.11 | 104.62 | *123.93* | W/K |

IES values have been calculated outside the software, using values of A, U and $c_m$ calculated by the software in the Apache Constructions Database. In IES, each construction is given a $c_m$ value; confusingly however this is not the same $c_m$ as in SAP, but is the kappa value, κ, as used in SAP, referring to the heat capacity of each construction. The much higher value of heat capacity in IES can be explained by the way it is calculated: IES uses the *specific heat capacity* of each material within a construction (e.g. specific heat capacity of sandstone is 1000 J/kgK), whereas the domestic model uses *heat capacity*, κ, of each construction (e.g. the κ of the external wall is 41 kJ/m$^2$K), also taken from CIBSE Guide A. The end result of these differences is that IES calculates a higher fabric heat loss, suggesting a greater requirement for space heating, while simultaneously implying that the walls have very high levels of thermal mass. The way IES calculates these parameters means it is not possible to assess the same level of thermal mass without significantly changing the U-values. The U-values have been kept the same as used in the SAP models as the primary target of this research is the SAP methodology. By allowing IES to calculate the thermal mass separately, it should highlight the differences between a steady-state and dynamic model more clearly.

As seen, the fabric heat loss variable remains similar across the methodologies. As has been questioned previously, the assumption of U-values (and therefore fabric heat loss) may cast doubt over the accuracy of the methods to determine energy consumption (Kelly, et al., 2012). The overall fabric heat loss calculated by the methodologies shown in Table 4.1 suggests that SAP 2009 should predict the lowest space heating requirement and IES the highest if the U-values are significant. As Figure 4.1 shows, this is indeed the case for CS1.

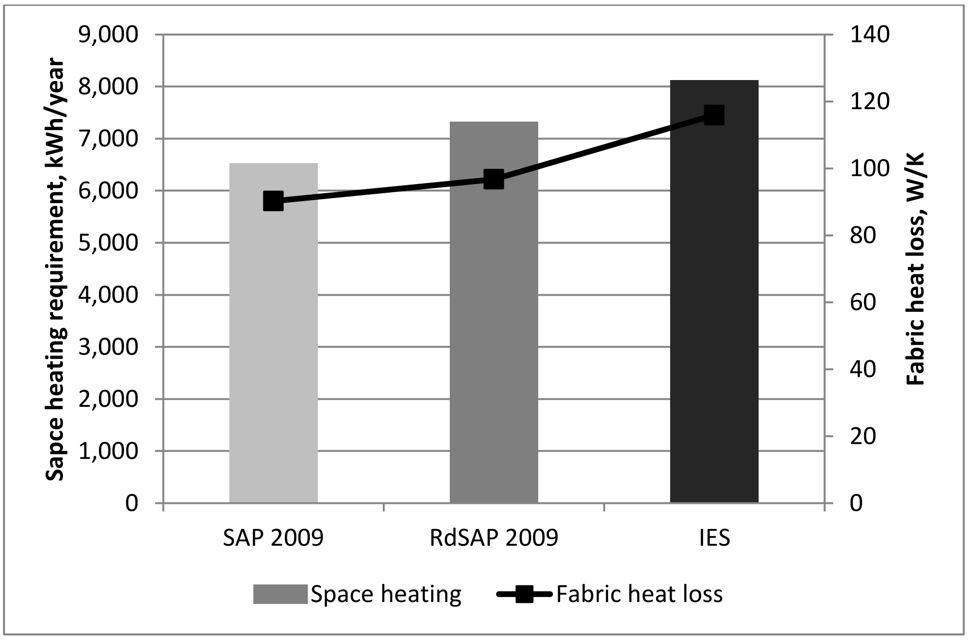


**Figure 4.1 Energy requirement by end use and calculation method**

As the U-values used are identical, these differences in space heating requirement across the methodologies could be due to the differences in the calculated area of external surfaces: SAP 2009 = 52.63m$^2$; RdSAP 2009 = 52.69m$^2$; IES = 56.94m$^2$. Whilst the difference in energy requirement between IES and SAP 2009 could be explained by a varying heat loss area, the heating requirement of RdSAP lies half way between the two while the heat loss area is similar to SAP 2009, suggesting that something besides the difference in heat loss area, and besides the assumed U-values is responsible for the difference in energy consumption. This will be looked at in greater detail in Chapter 5, ascertaining if similar conclusions are drawn from the following case studies, and reasons for the difference in end result between the methods will be sought.

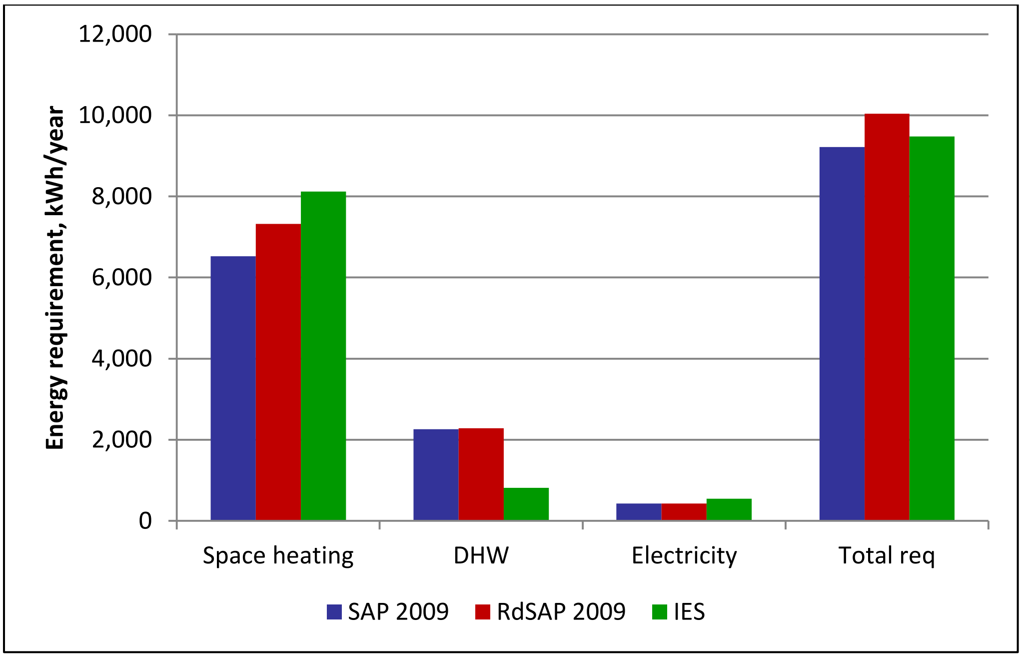


**Figure 4.2 Energy requirement by end-use for CS1**

By looking at the different users of energy in the home (excluding electrical appliances, not modelled by any of the methodologies here), it is clear that the energy requirement for the boiler dominates the total modelled energy requirement, but it can also be surmised from Figure 4.2 that it is the Domestic Hot Water (DHW) energy requirement that impacts on which method is seen as 'best' and 'worst', and requires further investigation, particularly with reference to the differences between the steady state methods and IES. Chapter 5 will discuss this result alongside the other case studies for further comparison and analysis for whether this finding is replicated in the other case study dwellings.

In considering the accuracy of the methodologies in representing real-life energy usage, the predicted values can be compared with those measured. What follows is this comparison for Case Study 1.

### *4.1.2 Predicted vs. measured space heating*

Comparing predicted energy requirement with measured energy usage should come with a note of caution with respect to the ability to directly compare the two. The predicted energy requirement is based upon a *standardised* occupancy, *standardised* heating regime, and other building characteristics noted by the assessor. Any difference between predicted and actual energy usage will depend upon the accuracy of those characteristics, and the occupants within the dwelling (see section 2.6). In the case of CS1, at least four factors will affect the energy requirement:

1. The occupants are energy aware, likely affecting their behaviour towards energy use;

2. A new boiler was installed a month prior to the data collection and the first few months of usage were during winter, there is potential it took time to get used to the new system;

3. One of the occupants works part time from home, so the times when the heating is required differs to that of the regime set by the National Calculation Methodology; and

4. The dwelling is in Edinburgh. This has a cooler climate than the SAP average thereby having a potentially greater space heating requirement, and has less daylight hours in winter and more in summer than the SAP average, again having an effect on the lighting and therefore electrical requirement.

When comparing space heating, all four points above should be taken into consideration and it should also be noted that while the models calculate the space heating and DHW requirements separately, the meter readings combine the two. Therefore Figure 4.3 displays the monthly fuel requirement (space heating and DHW combined) predicted by SAP 2009, RdSAP 2009 and IES with the actual mains gas usage as collated by the home owner.

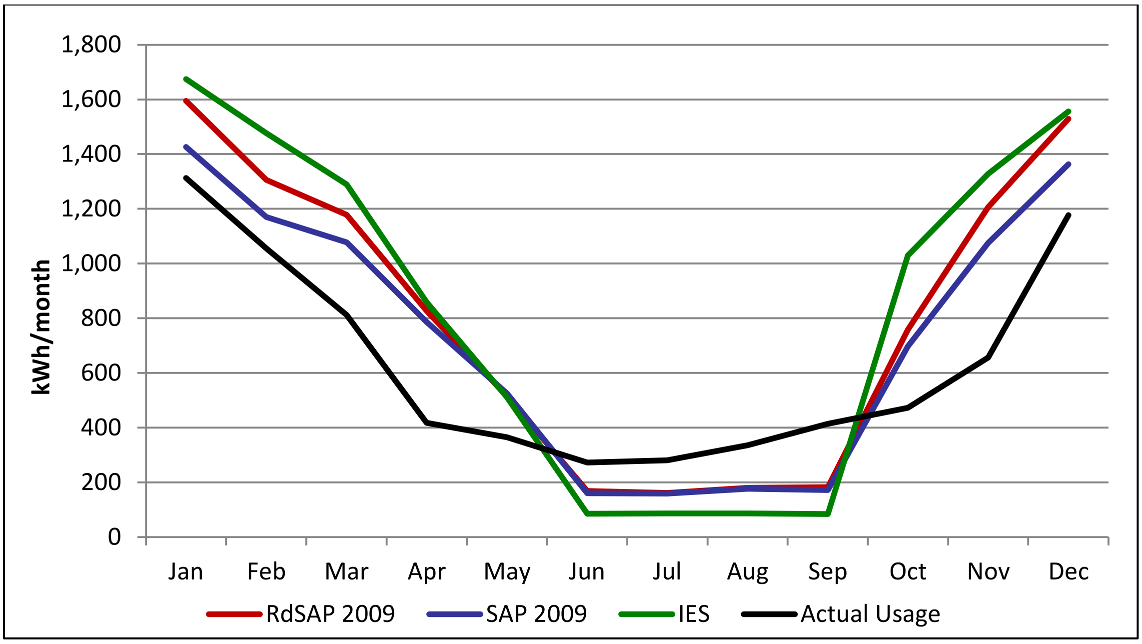


**Figure 4.3 Predicted and measured energy requirement for CS1 in 2011: space heating and domestic hot water**

What is immediately obvious is that there is little difference between RdSAP and SAP, despite the differences in values used in the calculation, although there is a slightly larger difference during the winter. The low and consistent values in June, July, August and September are due to all three models assuming zero space heating during these months; the residual requirement is that of the DHW system. The DHW calculated by IES is roughly half that of the RdSAP and SAP predictions. The actual usage is higher than the steady state models during the summer; this is most likely due to the requirement for space heating during some of these months, relating to point 4 above. During the traditional heating season (October – May), the IES modelled mains gas requirement matches less closely to the actual usage than the steady state models. This could be the dynamic nature of IES or because IES is using the local climate which would suggest greater heating demand than SAP's UK average climate. Conversely, the more accurate climate suggests far greater heating than is actually used, for which points 1 and 3 above may go toward explaining.

To explore this issue further, the climates used in the methodologies have been analysed. Figure 4.4 highlights the differences between the:

- UK climate used in SAP/RdSAP across the year, from the SAP 2009 documentation;

- Monthly average regional temperature as used in IES, from the half hourly temperature file for Dundee, the nearest site available, averaged across each month;
- Climatic average minima and maxima for the region, using Met Office climate data for the Edinburgh Gogarbank observation station, the nearest site available (Met Office, 2012); and
- Also included is the regional temperature as could be utilised by SAP, taken from the most recent edition of RdSAP (BRE, 2011).

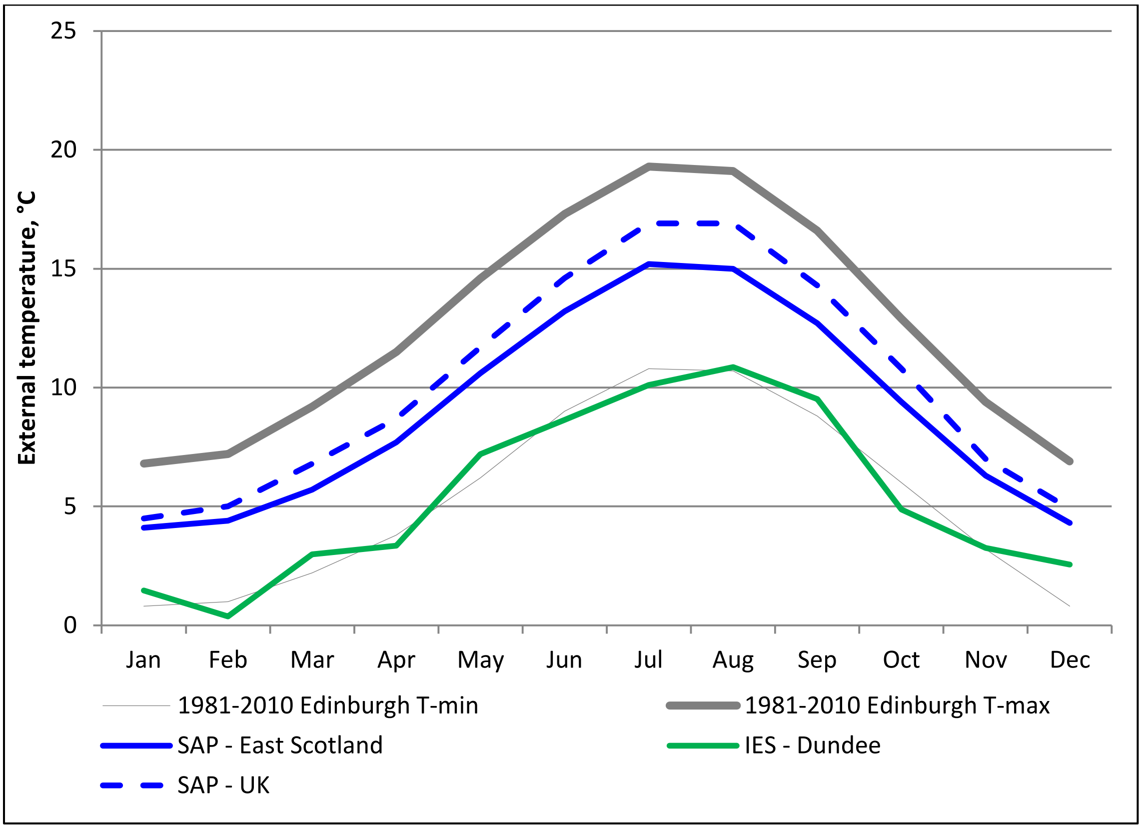


**Figure 4.4 External temperature as used in the methodologies**

It is immediately obvious that the IES weather file will always predict greater space heating requirement, if based on external temperatures, using temperatures cooler than SAP uses, and being much nearer the minimum climate temperatures seen in the region. This may be a strategy to provide the IES client with a 'worse-case scenario' heating requirement, but certainly wouldn't help a client requiring predictions of cooling load. The following charts suggest the space heating requirement when calculated in the three methodologies, using the Edinburgh and UK climate. For the UK climate, the UK average as given in SAP is used (see section 3.6), therefore the Leeds weather file was chosen to use in IES. In each chart, the solid lines represent the climate as used by an assessor, the dashed lines indicating the space heating requirement associated with a forced climate.

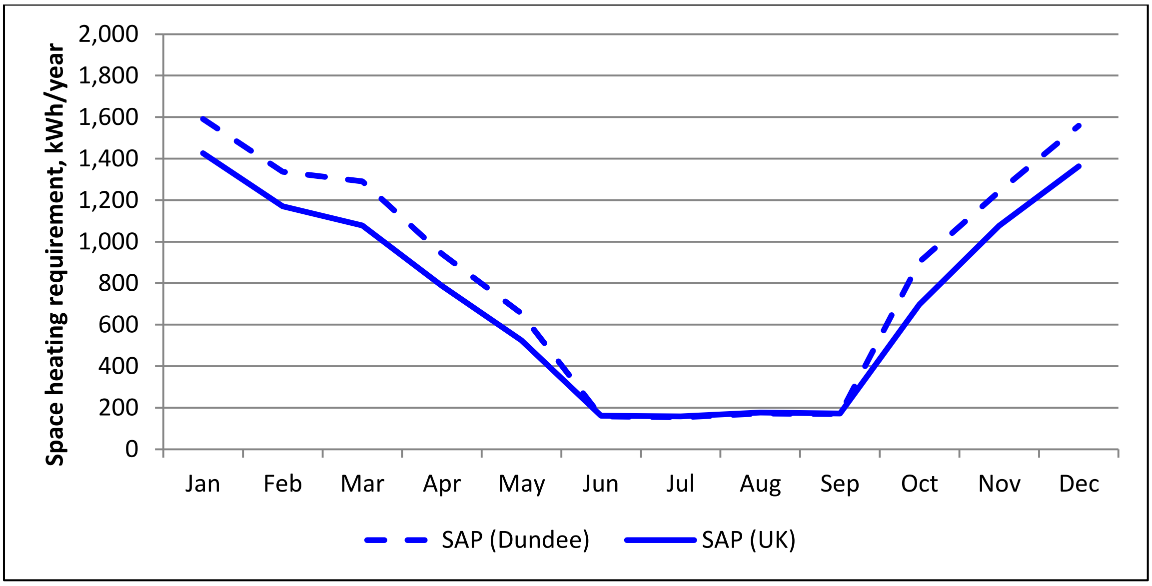


**Figure 4.5 Space heating requirement by location - SAP**

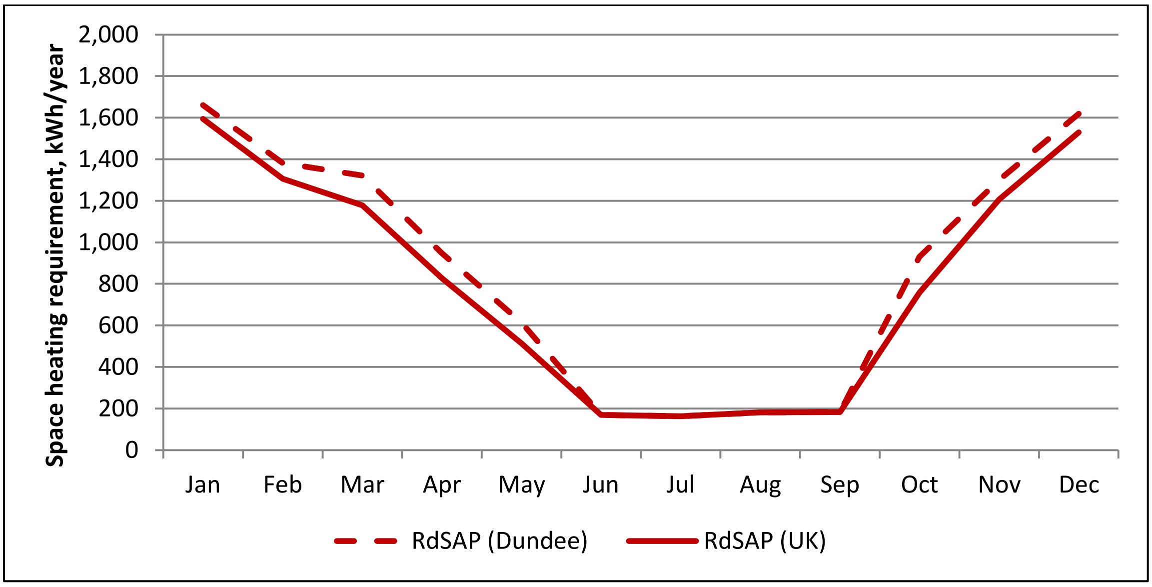


**Figure 4.6 Space heating requirement by location - RdSAP**

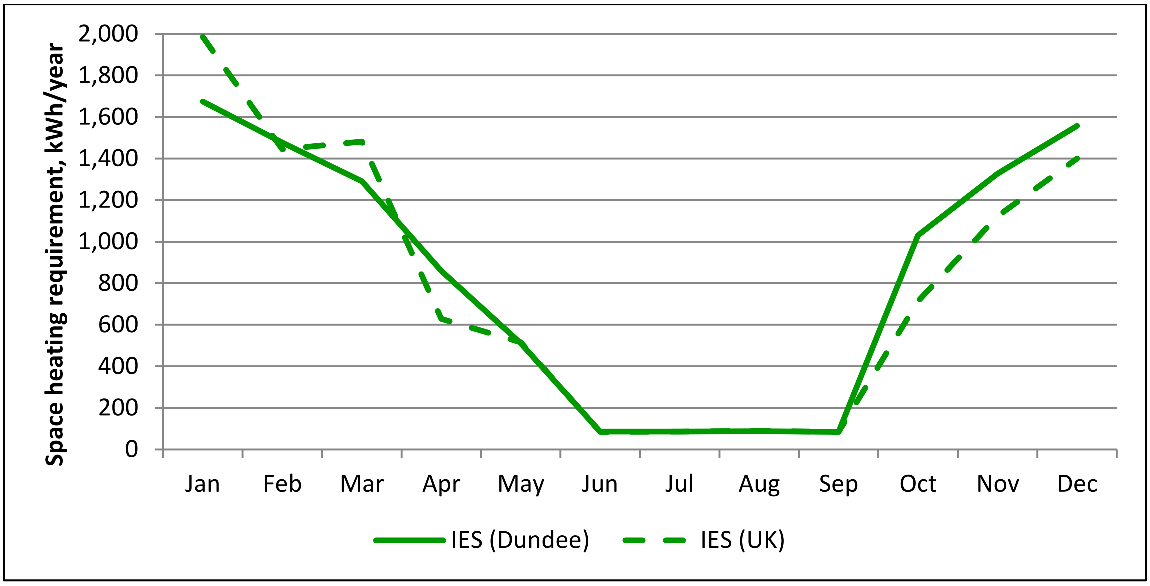


**Figure 4.7 Space heating requirement by location - IES**

Figure 4.5 to Figure 4.7 shows the three methodologies agree that a UK climate gives a lower space heating requirement, which is intuitive, given the location of the "UK average" 190 miles south of Edinburgh. It is therefore suggested that the difference in space heating requirement for CS1 between the steady state and dynamic methodologies is due to the different climates used.

The climate across the UK differs not only in terms of temperature, but also the level of sunlight available. In the steady state models, global solar radiation levels affect the level of 'solar gains', which are used to calculate the internal temperature and therefore the heating requirement. However, the location and level of sunlight are not included in the calculation for levels of daylighting, which impacts on electricity use.

### *4.1.3 Predicted vs. measured electrical usage*

The electrical use in all three methodologies includes that for lighting, ventilation equipment and central heating pumps and fans, therefore direct comparison is available between calculations. The electricity data recorded by the homeowner includes lighting, cooking, appliances and all electrical equipment in the dwelling and is therefore total electricity usage with no distinction between end use, so it is expected that the measured values be higher than those predicted. Figure 4.8 shows these comparisons.

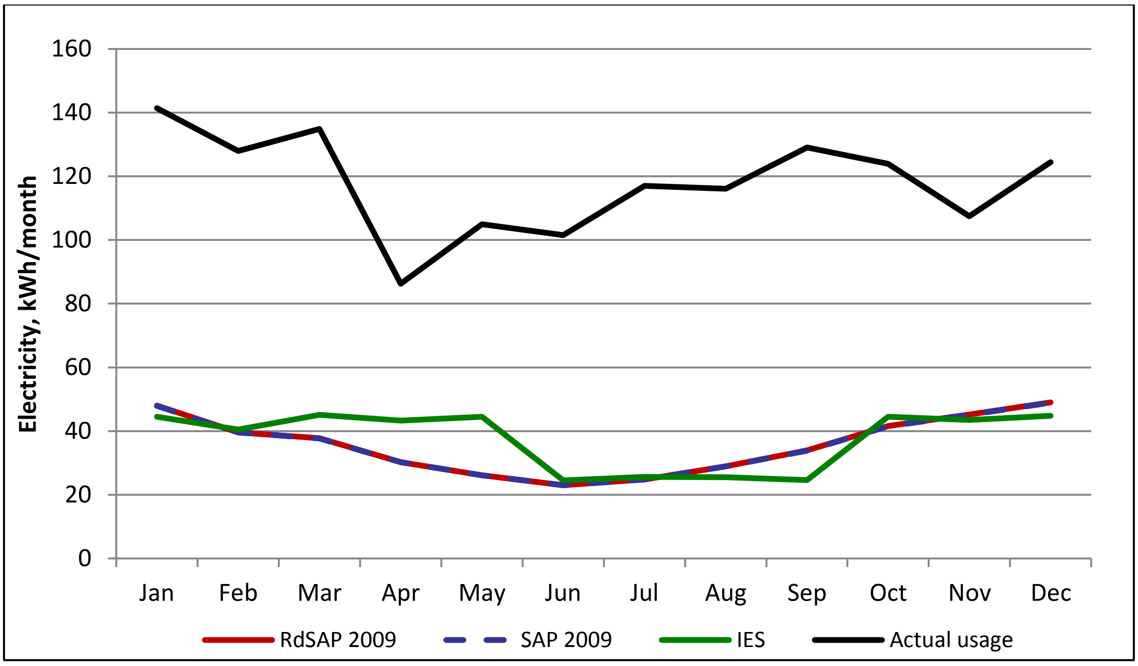


**Figure 4.8 Predicted and measured electricity (2011) usage for CS1**

As expected, the actual usage is much higher than the predicted requirement of any methodology. The sharp decline in electricity usage in April is due to the occupants being away for two weeks. Interviews with the occupants identify that the dip in electricity usage in November cannot have been due to occupant absence, so alternative reasons are sought. The weather station at the Royal Botanical Gardens in Edinburgh shows that November 2011 was drier and sunnier than the 1976-2005 climatic averages which may have impacted on lighting use in the dwelling (Royal Botanic Garden Edinburgh, 2012). However no other reasons can be identified, suggesting occupant behaviour may have been solely responsible for the dip in electricity usage.

It is seen that the electricity predicted by SAP and RdSAP are the same, despite the expectation that the assumed window size in RdSAP would lead to different daylight levels and therefore different lighting requirements. However, window area is a minor contributor to the calculation for daylight levels that its effect on lighting requirement is minimal, at just 0.65kWh/year.

The IES predicted electrical requirement mirrors the space heating requirement, in that it levels off during the summer months. This suggests that the electrical load is due mainly to the space heating system. Further investigation into the IES model for CS1 shows that the heating system electrical demand stays consistent across the heating months, and drops to zero during the summer. The lighting demand remains relatively consistent throughout the year, responsible for between 56 and 58% of electrical demand. So across the year the lighting is responsible for more electricity than the heating requirement, but the heating requirement shapes the demand profile.

By comparing the electrical usage with predicted requirement, it has been seen how important it is to have a complete picture of a dwelling. No single methodology captures a true representation of energy use, primarily due to the occupant's energy use, but partly due to each methods calculation.

The findings from CS1 with respect to lighting and space heating energy are unexpected and have challenged the main hypotheses, but it must be remembered that this mid-terrace, mid-floor tenement is a small dwelling, with very low heat loss area. The methodologies therefore need to be tested using a much larger, more complex dwelling.

## 4.2 Case Study 2 – Large detached house

### *4.2.1 Heating zones*

One such dwelling is a former Laird's house, comprising 4 storeys, at just over 360m$^2$ the floor area of CS2 is much larger than any other case study, and the heat loss area is also much larger as it is a detached dwelling. As the dwelling is split over multiple stories, a lower heat loss area per area of floor is experienced than other dwellings in this research (comparison across case studies is carried out in Chapter 5). This large floor area challenges many aspects of the models to accurately represent the energy usage as so much of the calculation relies on the total floor area. As the dwelling is now used as offices, comparison with actual data is not practical.

Comparing the energy users shows that space heating is the most significant energy user across the three assessment methodologies (Figure 4.9). Many variables are important to space heating requirement, a selection are explored here.

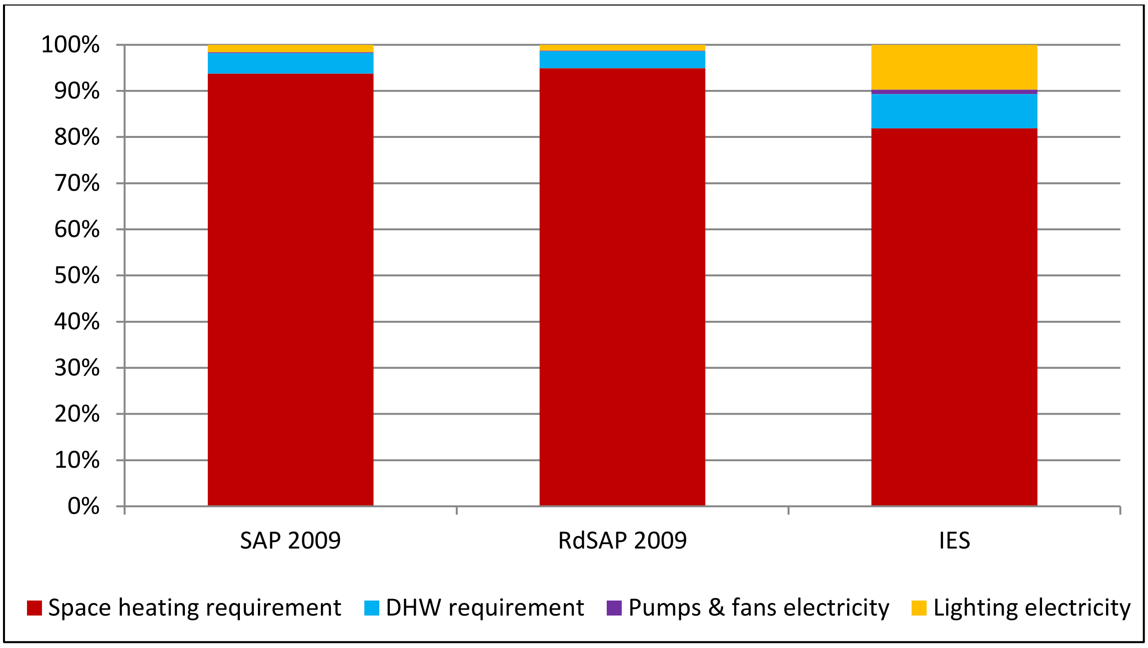


**Figure 4.9 Breakdown of modelled energy requirement for CS2**

At the heart of all space heating calculations is the internal temperature desired. In the steady state models, a temperature of 21°C is required to heat the "living area" (typically, but not always, the living room), and 18°C elsewhere. In IES, each room is assigned an activity, e.g. bathroom, dining room, kitchen, hall, living room etc. Each activity has a unique thermal profile with hours of occupancy, hours of lighting, and heating set point and regime (the values from SAP are mirrored). With help from previous occupants an approximate evaluation of room activity was applied, and is shown in Figure 4.10 (Hull, 2012) and (Ainslie, 2012). In SAP, the fraction of floor area designated living area is calculated from the individual room dimensions. In RdSAP, the living area is assumed dependant on the number of habitable rooms.

The total room count for CS2 is 16, with seven habitable rooms. This included more than one living room on more than one storey, giving a living area fraction ($f_{LA}$) in SAP of 0.24 ($88m^2$) and 0.16 ($58m^2$) in RdSAP.

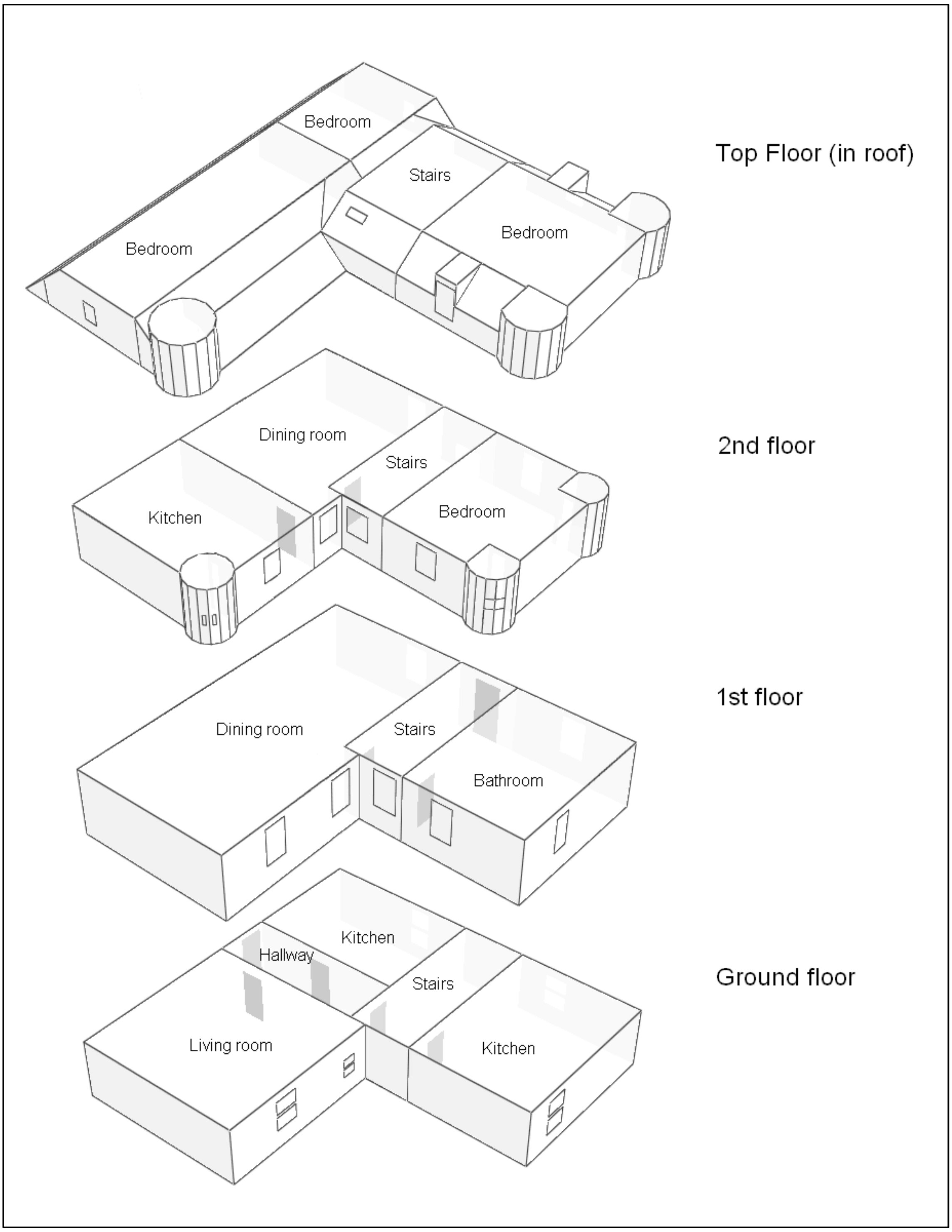


**Figure 4.10 Activity zones used in IES for CS2**

With a larger living room heated to the higher temperature, it was expected that the predicted space heating demand for CS2 would be higher in SAP and IES than the RdSAP methods, however as shown below in Figure 4.11 this is not the case.  To investigate, the RdSAP calculations were forced to use the larger SAP living room fraction of 0.24, to ascertain a quantifiable impact on space heating demand directly attributable to the living area fraction. As would be expected, the space heating demand increased. However, the increase of 2.39% would equate to an increase in cost of heating of £68 on a £3,044 bill. This is a very small increase on such a large inefficient property, so while it is clear that space heating has a significant part to play in overall energy use within such a dwelling, it is found that for this case study, the living area fraction is not of primary concern within the calculation.

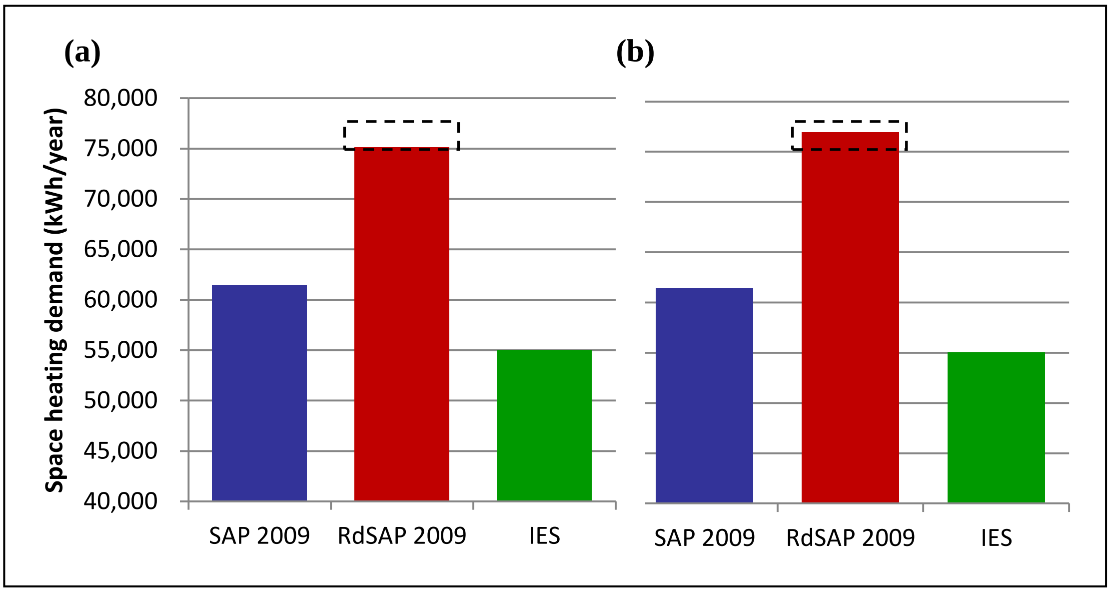


**Figure 4.11 Annual space heating demand using (a) SAP and IES $f_{LA}$ = 0.24 and RdSAP $f_{LA}$ = 0.16 as per assessment guidelines; (b) all methods $f_{LA}$ = 0.24; with the difference highlighted.**

In larger properties, while the number of occupants increases linearly (as will be shown in 4.2.4), the living room area in all likelihood does not increase linearly, as it is likely to remain a single room. CS2, with its multiple spaces as living rooms is a rare case, and highlights the individual nature of dwellings and the shortcomings of generalising dwelling usage for energy assessment.

Having assessed whether the $f_{LA}$ assumption (and therefore the internal temperature required throughout the dwelling) is responsible for such a large heating requirement and found it to be insignificant in this particular case study, alternative reasons are pursued. In section 4.1, a case study with a small heat loss area was assessed and it was proposed that the assumption of U-values was not significant, using CS2 it will be seen if the same can be said for a larger dwelling.

### *4.2.2 Heat loss*

In addition to modelling CS2 in the three methodologies as built, to ascertain the importance of the assumed U-values, the calculations have been repeated in RdSAP using a value for traditional stone walls from (Baker, 2011), of 1.1W/m$^2$K, in comparison to the 1.5W/m$^2$K assumed by RdSAP.

**Table 4.2 Effect of altered wall U-value in RdSAP for CS2**

| **Output** | | **Wall U-value 1.5W/m$^2$K** | **Wall U-value 1.1W/m$^2$K** |
|---|---|---|---|
| DHW fuel requirement | kWh/year | 4,831 | 4,831 |
| Space heating requirement | kWh/year | 124,162 | 115,111 |
| (Total) Fuel cost | £/year | 4,458 | 4,167 |
| SAP value (rating) | | 31 (F) | 34 (F) |
| Environmental Impact | | 23 | 26 |

The results summarised in Table 4.2 indicate that the “improvement” in U-value by 27% reduces the space heating requirement by approximately 8% for this dwelling. If an in-situ U-value was used at this property, it could be suggested that while the assessment was more accurate (by using more accurate input), it would receive the same ‘F’ SAP rating. It is seen from this example calculation, that there will be error in the calculated results unless in-situ measurements are used, but that the heat loss is not the sole reason for the high space heating requirement.

### *4.2.3 System efficiency*

It is clear that CS2 has a large demand for space heating, with a dwelling volume of 850m$^3$ (in comparison to CS1 at 194m$^3$). It has been seen that the effect of assumptions with regard to living room area and heat loss have an effect on this heat loss requirement, but neither of these effect with great significance the end result of the large fuel requirement. Therefore it is surmised that the most significant variable in estimating fuel requirement is that of the efficiency of the system itself. The dwelling currently uses two identical Ideal Concord CX40 47.3kW boilers for the heating and hot water. The space heating is via a network of radiators on each storey, only some of which have TRVs. The efficiency of the heating system comes both from the controls on the system, and the efficiency of the boilers, in this case both are antiquated and in need of upgrade. For example, if the boiler was updated to a modern condensing boiler, the system efficiency would increase (for example, using two Potterton Powermax HE 150CP boilers, having similar capacity to the current boilers) from 67.9% to 85.4%, an efficiency improvement of 20%. The associated heating requirement with such an improvement would be just 45,521kWh/year, a 63% reduction, with an associated SAP rating of 48.7(E). From this it is deduced that for this case study all end results, whether fuel requirement, running costs, SAP rating or EI rating, are reliant upon the heating system used.

### *4.2.4 Occupancy*

As briefly introduced above, a further challenge with energy assessment of large dwellings is that of the occupancy. In the steady state models occupancy is a function of the floor area, and it is the steady-state calculated occupancy level that is used in IES. The relationship between the floor area and occupancy in SAP and RdSAP is shown in Figure 4.12.

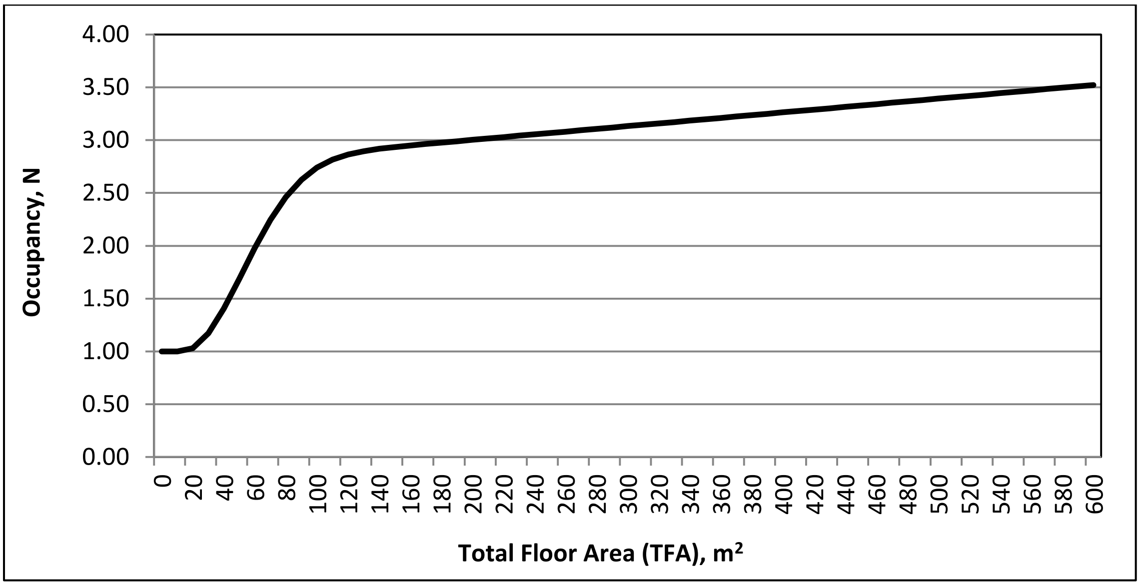


**Figure 4.12 Occupancy and TFA relationship**

It is obvious that for dwellings over 110m$^2$, the less impact on occupancy a greater floor area has, but for dwellings under 110m$^2$, a small change in floor area can have a large effect on the number of occupants; this will be discussed further to ascertain legitimacy of the calculation of occupancy across all case studies in Chapter 5. For this particular case study, the floor area indicates occupancy of 3.21 people, in both SAP and RdSAP 2009.

When the house was lived in as a single dwelling after 1920, the occupancy was 4 (Ainslie, 2012), but when the house was split in two after 1976, the occupancy doubled to 8 (Hull, 2012). For CS2, the SAP standardised figure of 3.21 is nearer the pre-1976 living situation, (as has been used for the case study).

To put the problem of standardised occupancy into perspective, the difference in real occupancy in later years is 100%, yet an assessment at 1926 and 1976 occupancy levels would have had the same energy rating. This is one area where the use of SAP and RdSAP in providing energy advice can be challenged, as significant areas of the calculation are based on the number of occupants: domestic hot water consumption; internal gains from hot water; appliance energy use; and appliance associated gains. As has been argued previously by Gill et al. (2010) and Andersen et al. (2009), the occupancy effect is one of the most significant in terms of total energy requirement of a dwelling, (although others disagree on the magnitude of such influence (Guerra Santin, et al., 2009)). Therefore, providing energy advice based on a standardised consumption pattern has weaknesses that can be solved with applying a more realistic occupancy, whether the current occupancy for energy advice, or using the standardised occupancy for potential future occupants.

With such a large building, with a significant demand and cost of space heating, refurbishment work may include reducing heat loss through the building fabric before upgrading the heating system as this research suggests would be of greater benefit to this particular case study. The following case studies explore what benefits such a refurbishment can provide when assessed within the limits of SAP, RdSAP and how the changes can alter the thermal behaviour of the dwelling, and if any of the methodologies will predict the sought after reduction in space heating cost.

## 4.3 Case Study 3 and 4 – Small detached house

Case Study 3 and 4 are a single small Garden Bothy in the west of Scotland. Part of the larger Dumfries House estate purchased in 2007 by a consortium of charities and heritage bodies, Historic Scotland are using the house to research energy modelling and retrofitting of traditionally constructed dwellings. As introduced in Section 3.2.3, CS3 uses the house pre-retrofit, and CS4 uses the house with the building fabric improvements and upgraded heating system. This provides the opportunity to investigate what impact changes could have when modelling a dwelling, and investigate whether the use of RdSAP and its associated assumptions is detrimental for a dwelling undergoing major energy performance renovations. Four aspects are focused on in this discussion: space heating requirement calculation nuances, energy use for lighting, internal temperature, and thermal mass.

### *4.3.1 Space heating*

Firstly, the space heating system prior to the refurbishment consisted of coal fires in the kitchen and living room (with a back boiler for hot water), with electric heaters in each bedroom. The way that SAP and RdSAP describe heating systems can be interpreted in two ways, the explanation and defence of the chosen systems follows.

In SAP 2009, the procedure for identifying which is the main heating system and which is the secondary comes from Appendix A2, as there is an adequate system present (heating in more than 25% of the habitable rooms) in this case study. The selection process for the main heating is shown in Figure 4.13.

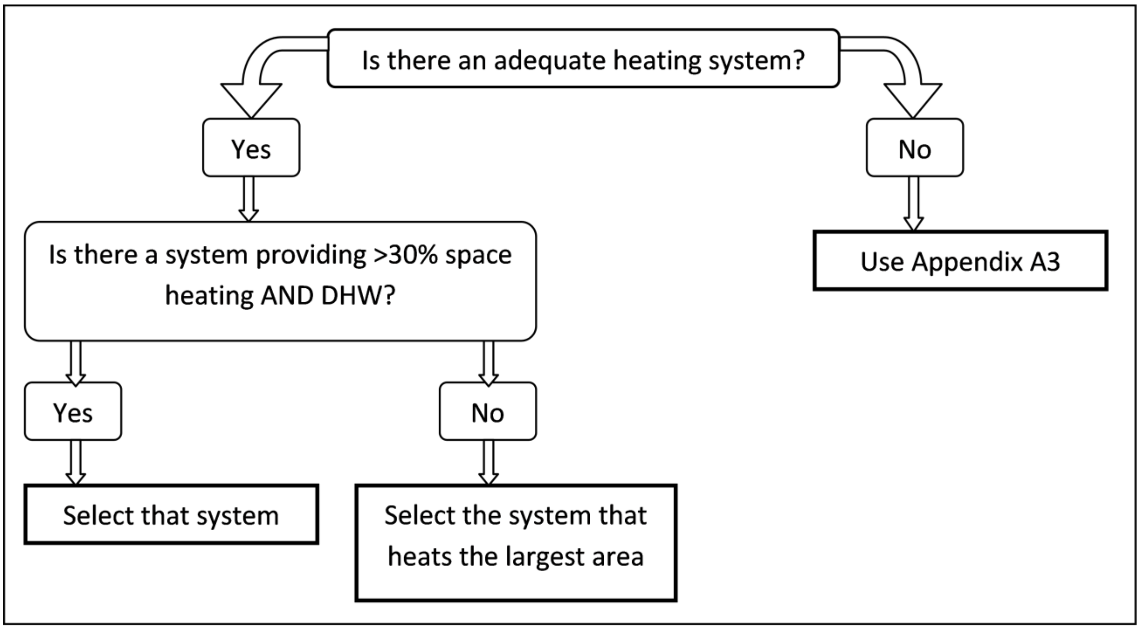


**Figure 4.13 Main heating system selection process in SAP 2009**

To select the secondary heating system Appendix A2 is still used, shown in Figure 4.14.

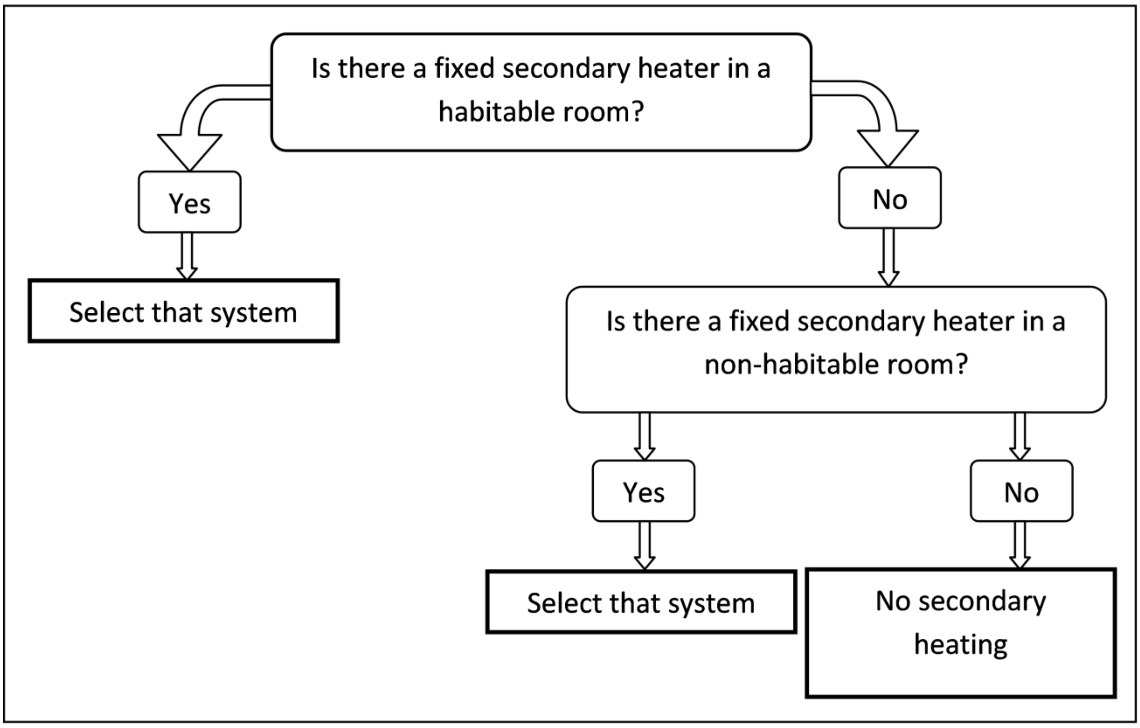


**Figure 4.14 Secondary heating system selection process in SAP 2009**

For CS3, the main heating system is therefore electric room heaters, with coal fires as secondary heating, as the kitchen is a non-habitable room as defined in SAP. The fraction of heating from the secondary system is also required, and depends on the main heating type, as indicated in Table 4.3. In this instance, because the main heating is electric room heaters, the proportion of secondary heating from the coal fires is 20%.

**Table 4.3 Fraction of heat supplied by secondary systems (Table 11 in SAP 2009)**

| Main heating system | Fraction from secondary |
|---|---|
| All gas, oil and solid fuel systems | 0.10 |
| Micro-cogeneration | See Appendix N |
| Heat pump, data from database | See Appendix N |
| Heat pump, data from Table 4a | 0.10 |
| Electric storage heaters (not integrated) | |
| -not fan assisted | 0.15 |
| -fan assisted | 0.10 |
| Integrated storage/direct-acting electric systems | 0.10 |
| Electric CPSU | 0.10 |
| Electric room heaters | 0.20 |
| Other electric systems | 0.10 |
| Community heating | 0.10 |

In RdSAP 2009, the system chosen uses the guidance in Appendix S, Section 10, which allows two main systems if different systems heat different parts of the dwelling, but a second main system should not be confused with a secondary system. Points to note (taken from Appendix S10.1, p128) include:

- Mains systems cannot be room heaters unless the dwelling's heating consists solely of room heaters
- If main system 1 heats all habitable rooms, there is no main system 2 unless it serves DHW only
- When there are two main systems, system 1 always heats the living room and:
    - Where two systems serve different spaces, the percentage recorded for each system is in proportion to the heated floor area served by each system;
    - Where two systems serve the same heating circuit the default assumption is a 50/50 split

With respect to secondary heating, Appendix S instructs the assessor to:

- Include a secondary heater if there is a fixed emitter present regardless of whether the main heating system(s) heat all rooms
- If more than one secondary heater:
    - Select the device that heats the greatest number of habitable rooms
    - If that does not resolve it, select the device using the cheapest fuel
    - If that does not resolve it, select the device with the lowest efficiency
- An open fireplace is to be considered if capable of supporting an open fire

In CS3, as the dwelling's heating consists solely of room heaters, the main system can be room heaters. No single heating system provides heat for all habitable rooms, therefore the system heating the living area is designated main system 1, the coal fires. However, RdSAP instructs the assessor that "A second main system is not to be confused with a secondary heater. The latter are room heater(s) heating individual room(s) either as a supplement to the main heating in the room…or for rooms not heated by the main system(s)." Therefore, the electric room heaters in the bedrooms are considered secondary, rather than a second main system.

There is therefore a difference in the space heating requirement between SAP and RdSAP 2009; this is referred to when discussing the results. The systems described in Table 4.4 are used here, but it has been chosen on the back of careful and lengthy consideration and it should be noted that a fellow assessor could interpret the guidelines differently, thereby making different system choices.

**Table 4.4 Heating systems used in SAP and RdSAP for CS3**

| | Main 1 | | Main 2 | Secondary | |
|---|---|---|---|---|---|
| | **Type** | **Fraction** | **Type** | **Type** | **Fraction** |
| **SAP** | Electric room heaters | 80% | None | Coal fire | 20% |
| **RdSAP** | Coal fire | 90% | None | Electric room heaters | 10% |

Because of the difference in heating systems applied, different efficiencies are applied to the demand, with electric heating given 100% efficiency, and coal fires 50%

efficiency. This leads to very different results for fuel requirement across the three methodologies, seen in Figure 4.15.

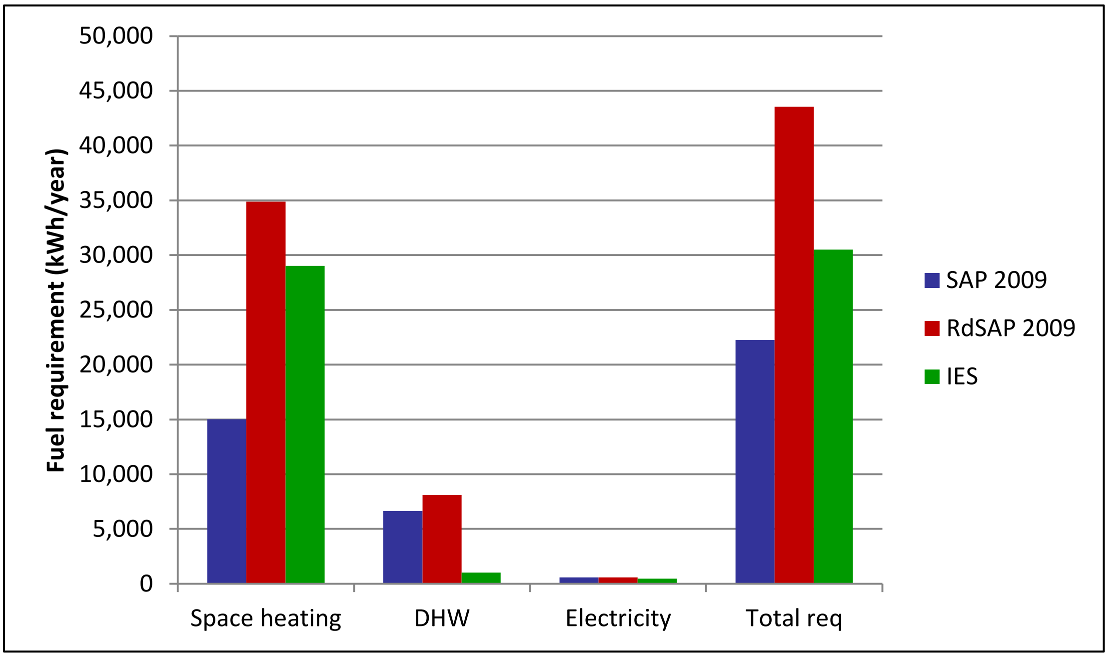


**Figure 4.15 Fuel requirement for CS3**

**Because of the different heating systems giving such different results for space heating *requirement* between *requirement* between models, the *demand* is compared instead, shown in**

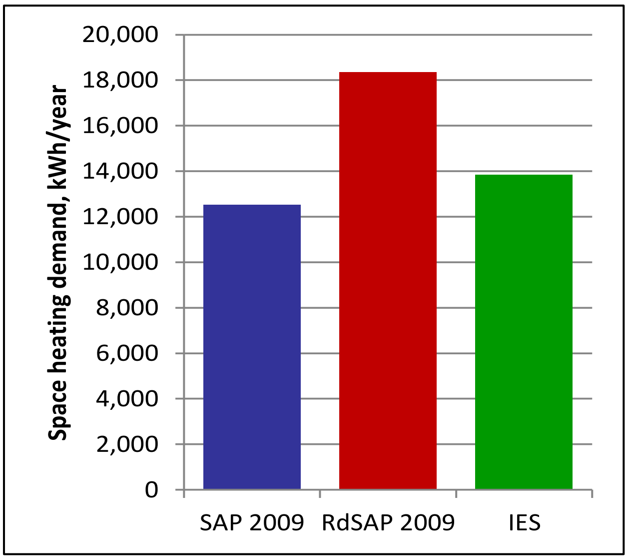


Figure 4.16.

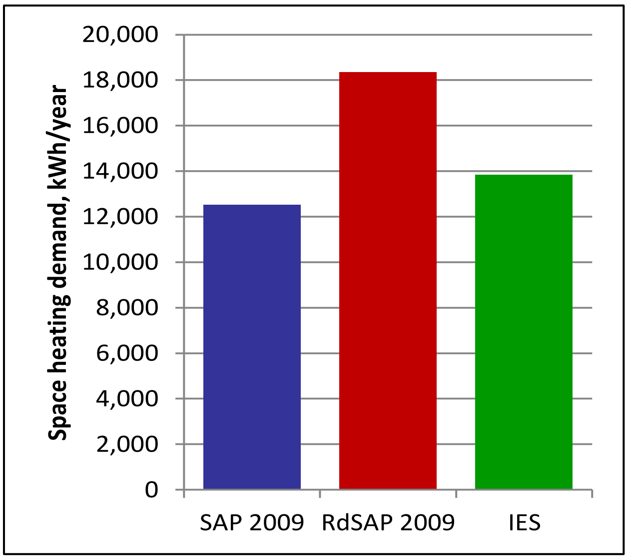


**Figure 4.16 Space heating demand for CS3**

The RdSAP 2009 methodology estimates the highest demand for space heating, which as Figure 4.15 indicated is the dominant energy user in CS3. Like CS2, the dwelling is a detached dwelling, increasing the area of heat loss, with high levels of heat loss through the wall. In this instance it is seen that the IES methodology estimates space heating demand nearer that of SAP 2009 than RdSAP 2009. As SAP and IES both use more detailed information in the calculation, this could have been expected.

In these first three case studies it is already clear that the differences between methodology results depend on the dwelling type, with no single methodology consistently giving the highest or lowest estimated energy requirement.

In CS4, the heating system selection is far simpler, with the introduction of the biomass central heating and hot water system. The refurbishment inclusion of a biomass heating system introduces a further point of interest with respect to the understanding of Energy Performance Certificates and therefore their efficacy. The SAP rating given in the 'rainbow' rating is a measure of cost, and as seen with CS2, is therefore also a measure of energy efficiency. If moving from an old inefficient gas boiler (e.g. 72%) to a new biomass boiler (with efficiency of 65% as given in SAP Table 4), the fuel requirement would actually increase.

In CS4, the efficiency for the main system reduces within SAP 2009 while the efficiency for the secondary system increases, resulting in a slight decrease in space heating requirement – see full results for the two case studies and the two steady state methodologies in Table 4.5. However, as the new system fuel is far less carbon intensive, there are significant $CO_2$ savings. The biomass pellets are more expensive than coal but cheaper than electricity, leading to a decrease in cost for the homeowner. What is important however is that while the homeowner saves £485 a year on bills, and reduces the dwelling emissions by 86%, the SAP rating only improves from a G to an F.

**Table 4.5 Space heating system comparisons - CS3 and CS4**

| **SAP 2009** | **CS3** | **CS4** |
|---|---|---|
| System | Room heaters | Central heating with radiators<br>And room heaters |
| Fuel | Main = Electric<br>Secondary = Coal | Main = Biomass pellets<br>Secondary = Electric |
| Efficiency | Main = 100%<br>Secondary = 50% | Main = 65%<br>Secondary = 100% |
| Fuel requirement | **12,524 kWh/year** | **10,185 kWh/year** |
| Associated $CO_2$ | 8,990 $kgCO_2$/year | 1,242 $kgCO_2$/year |
| Cost | **£1,297** | **£812** |
| **RdSAP 2009** | **CS3** | **CS4** |
| System | Room heaters | Central heating with radiators<br>And room heaters |
| Fuel | Main = Coal<br>Secondary = Electric | Main = Biomass pellets<br>Secondary = Electric |
| Efficiency | Main = 50%<br>Secondary = 100% | Main = 65%<br>Secondary = 100% |
| Fuel requirement | **18,354 kWh/year** | **10,205 kWh/year** |
| Associated $CO_2$ | 13,624 $kgCO_2$/year | 1,240 $kgCO_2$/year |
| Cost | **£1,192** | **£814** |
| **IES** | **CS3** | **CS4** |

| | | |
|---|---|---|
| System | Room heaters as per dwelling | Central heating with radiators |
| Fuel | Coal and<br>Electric | Biomass pellets |
| Efficiency | Coal fires = 50%<br>Electric heaters = 100% | 65% |
| Fuel requirement | **13,835 kWh/year** | **8,540 kWh/year** |
| Associated $CO_2$ | 11,002 kg$CO_2$/year | 331 kg$CO_2$/year |
| Cost | **£1,233** | **£583** |

When using RdSAP 2009 for CS4, the efficiency of the main system increases, and the secondary system remains at 100% efficiency (according to SAP guidance for electric systems). There is consequently a greater reduction in fuel requirement (44%) than in SAP 2009 (19%). As coal has far greater carbon intensity than biomass pellets, the RdSAP calculated $CO_2$ emissions of CS3 are greater than in SAP, therefore the reduction in $CO_2$ from CS3 to CS4 is larger, at 91%. The cost of the space heating system in RdSAP is similar to that in SAP, with a calculated saving of £378 per year.

The estimated fuel requirement from IES for CS3 lies nearer that of SAP 2009, much lower than RdSAP 2009. For CS4 however, the predicted fuel requirement in IES is lower than both SAP and RdSAP 2009. Remembering the input information has been the same, this difference must be down to the calculation methodology used in IES. Similarly to SAP and RdSAP 2009, a large saving in $CO_2$ is estimated, although at just under 97% this is the highest estimate $CO_2$ saving of the three methodologies. The same is seen with the space heating cost, a large saving, but larger than the steady state methodologies estimate.

This focus on space heating requirement, demand, and reductions in both when refurbished, whilst significant in terms of end energy use, should not be taken as the only savings available for the comparison of these two dwellings.

#### *4.3.2 Lighting energy*

As outlined in Section 3.5.10, there are methodology differences for calculating electricity requirement for lighting. The dynamic method is based on occupancy and activity in each room, whilst SAP is dependent upon the length of the month and the level of daylight available. The effect of these differences is shown in Figure 4.17.

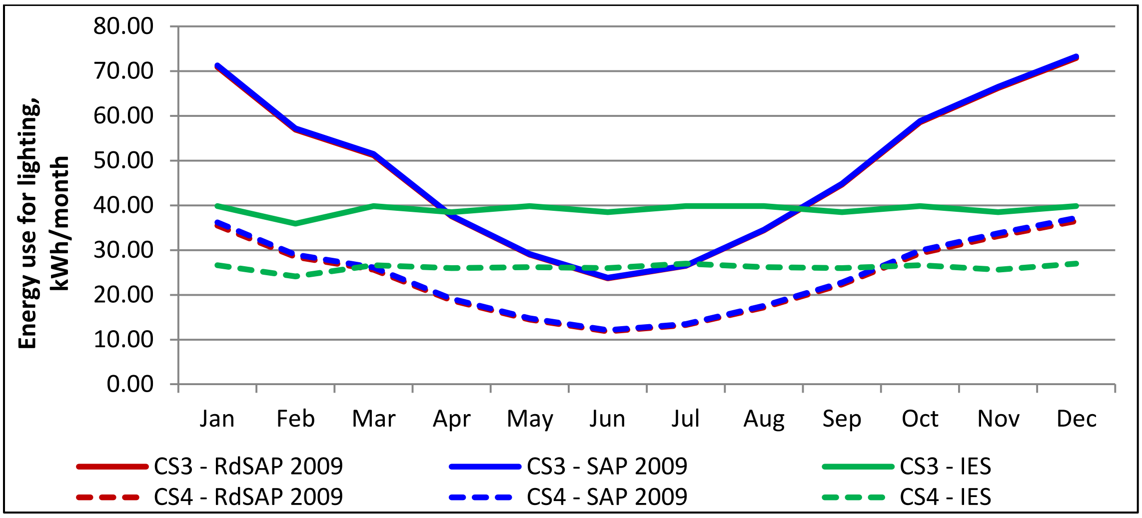


**Figure 4.17 Predicted energy for lighting, CS3 and CS4**

In the dynamic method, the requirement does not vary according to the season, as the advanced model within IES calculating daylight has not been used in this case. The slight variation in energy requirement is due to the number of days in the month. The variation across the SAP and RdSAP results are due to the cosine function used within Equation 3.17.

The reduction in energy requirement post-retrofit (with 100% low energy lighting) is clear, but appears to show a more pronounced reduction in the colder months. This is a result of the cosine function used by SAP to break the annual energy down into monthly values: the higher the initial energy, the larger the variation across the year, giving the impression on the chart of a convergence and divergence across the year. This is not seen in the IES values, as this is a simple reduction in energy used per hour each month.

Comparing the change in energy requirement pre- and post-retrofit, a percentage reduction has been calculated, shown in Figure 4.18. Where IES has the lowest initial energy requirement for lighting, it has the highest post-retrofit energy requirement for lighting; the percentage reduction is therefore the lowest. The reduction in both SAP and RdSAP is due to the ratio of low energy lights to normal lights, and associated correction factor, $C_1$. In CS3, the ratio is 0 and $C_1$ is 1. In CS4 the ratio is 1 and $C_1$ is

0.5, hence the 50% reduction in energy requirement. Because the energy requirement in IES is more complex, the reduction is less straightforward.

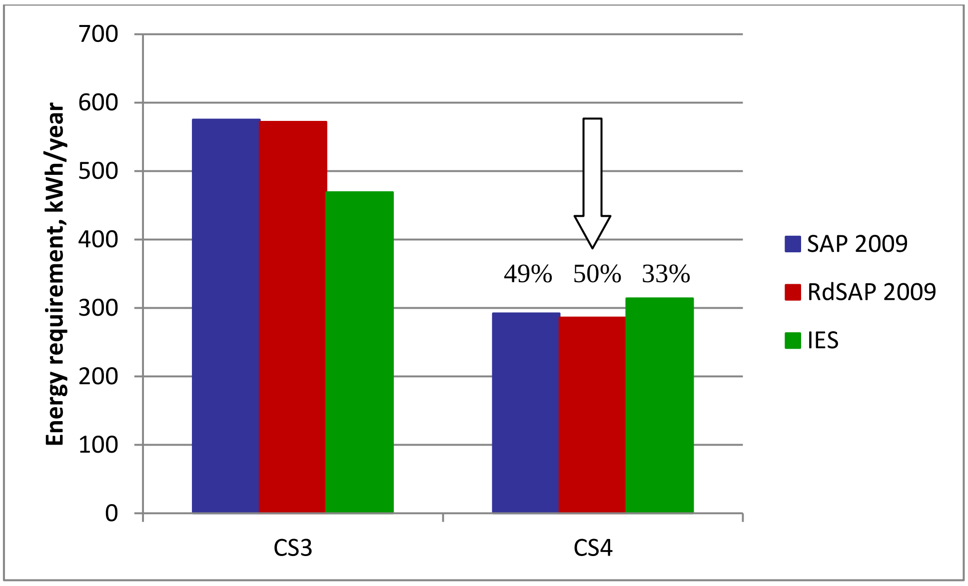


**Figure 4.18 Annual lighting requirement, before and after retrofit**

### *4.3.3 Internal temperature*

These differences in lighting *energy* also impact on the level of *gains* from the lighting, which then impacts on the internal temperature of the dwelling. Figure 4.19 identifies the differences between the three methodologies, both pre- and post-retrofit. Throughout the year in both case studies, RdSAP 2009 calculates the highest gains, with IES calculating the least. The retrofit options have clearly impacted on the assessed level of gains, reducing them in all three methodologies. This reduction is due to the following:

- Old lighting replaced by efficient low-energy lighting
- Introduction of a thermal store and pipe insulation for the DHW
- Single glazed windows replaced with double glazing

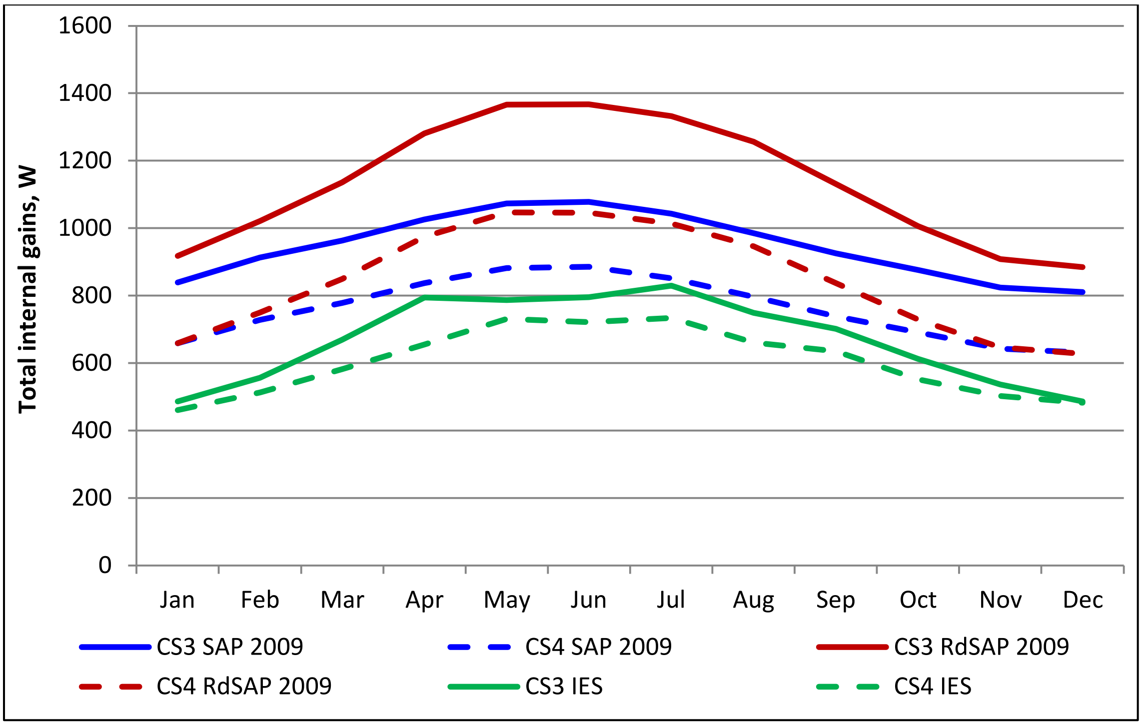


**Figure 4.19 Total internal gains pre- and post-retrofit**

An example of the breakdown of the internal gains that differ between CS3 and CS4 is shown in Table 4.6, using the results from SAP 2009 as an example. The 'total gains' values also include those gains that do not change between the two case studies: metabolic, appliances, cooking and pumps and fans.

**Table 4.6 SAP 2009 internal gains pre (CS3) and post (CS4) retrofit. All values in Watts.**

| | Type | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CS3 | **Lighting** | 81 | 72 | 58 | 44 | 33 | 28 | 30 | 39 | 52 | 67 | 78 | 83 |
| CS4 | | 41 | 36 | 29 | 22 | 16 | 14 | 15 | 20 | 26 | 34 | 39 | 42 |
| CS3 | **DHW** | 272 | 269 | 265 | 259 | 256 | 251 | 246 | 252 | 254 | 260 | 266 | 269 |
| CS4 | | 154 | 151 | 147 | 141 | 138 | 133 | 128 | 134 | 136 | 142 | 148 | 151 |
| CS3 | **Solar** | 112 | 195 | 270 | 368 | 450 | 482 | 462 | 392 | 309 | 224 | 135 | 96 |
| CS4 | | 100 | 174 | 242 | 329 | 402 | 431 | 413 | 350 | 276 | 200 | 121 | 85 |
| CS3 | **Total** | 838 | 912 | 963 | 1025 | 1073 | 1078 | 1043 | 985 | 925 | 875 | 823 | 810 |
| CS4 | | 658 | 728 | 778 | 837 | 881 | 885 | 851 | 796 | 738 | 690 | 642 | 630 |

These gains are directly responsible in the SAP and RdSAP 2009 calculations for calculating the internal temperature, $T_i$, of a dwelling. The $T_i$ is split into two zones reflecting the living room and ‘rest of dwelling’ similar to the space heating calculations. Using IES, half-hourly values for $T_i$ are available for the living room and a room that represents the ‘rest of dwelling’, in this case, a bedroom (Figure 4.20 and Figure 4.21). The bedroom is a similar size to the living room, and has approximately the same area of heat loss (although from the roof rather than the floor), and while having a similar area of south-facing wall, the bedroom has no south-facing window while the living room does have a south facing window. This will have impacted on the difference in solar gain between the two rooms.

The following charts show the difference between a summer week and a winter week; the particular weeks were chosen as having the shortest and longest days, June and December 21st, as these two weeks provide a 6 month difference in climate information. In each chart, the cooler minimum temperature in winter is seen, as well as the effect that the heating has on the internal temperatures, bringing them up to the temperatures specified by the model: 21°C in the living room, and 18°C elsewhere. The same pattern across the June week can be seen in both rooms, with a range during these particular weeks of approximately 16-19°C in the bedroom, and slightly more pronounced in the living room (16-21°C). In the winter, the same pattern of temperature change is seen in each room due to the heating system, but again, the diurnal variation is more pronounced in the living room, reaching cooler temperatures than the bedroom.

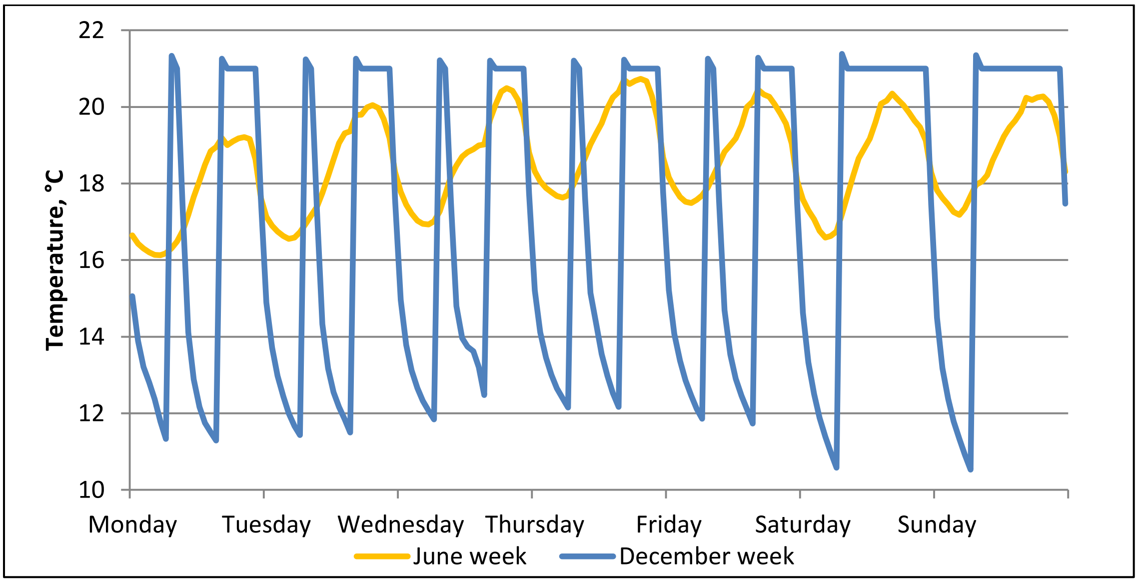


**Figure 4.20 Example living room temperature in CS3**

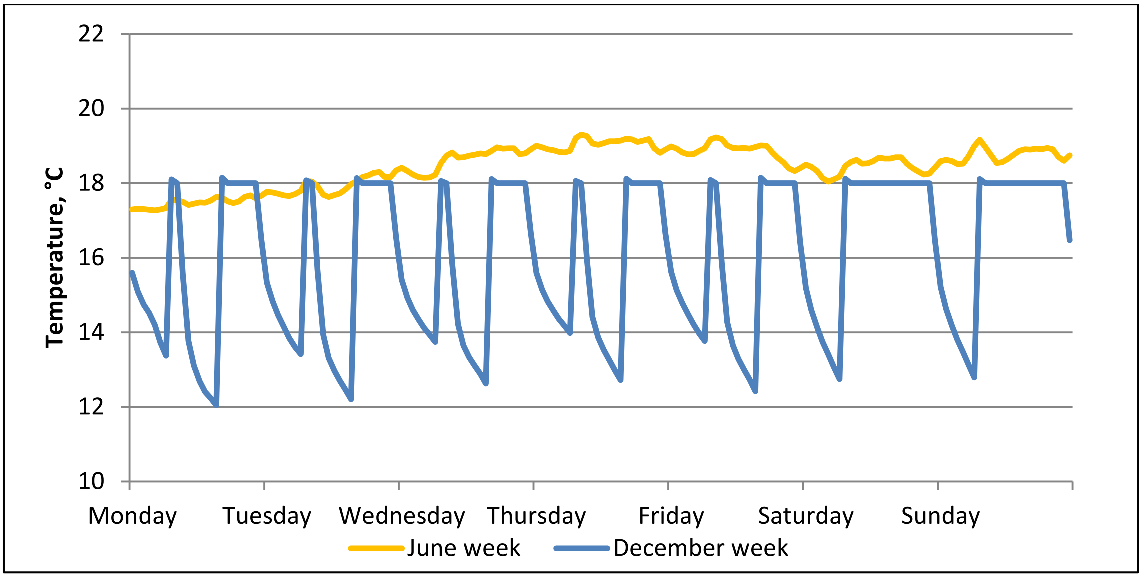


**Figure 4.21 Example 'rest of dwelling' temperature in CS3**

The same figures can be produced for CS4. The effect of the retrofit measures on the living room temperatures appears to be that of stabilisation, with the diurnal variation less in both seasons (Figure 4.22). However, whilst the winter temperatures have increased, the internal temperature during the summer has reduced: still with a 3°C variation, the range has reduced to 13-16°C. In the bedroom, the temperature has stabilised in the summer at a slightly lower temperature (Figure 4.23). In the winter, the temperature variation is reduced by the retrofit measures, but a lower minimum is reached, just over 11°C.

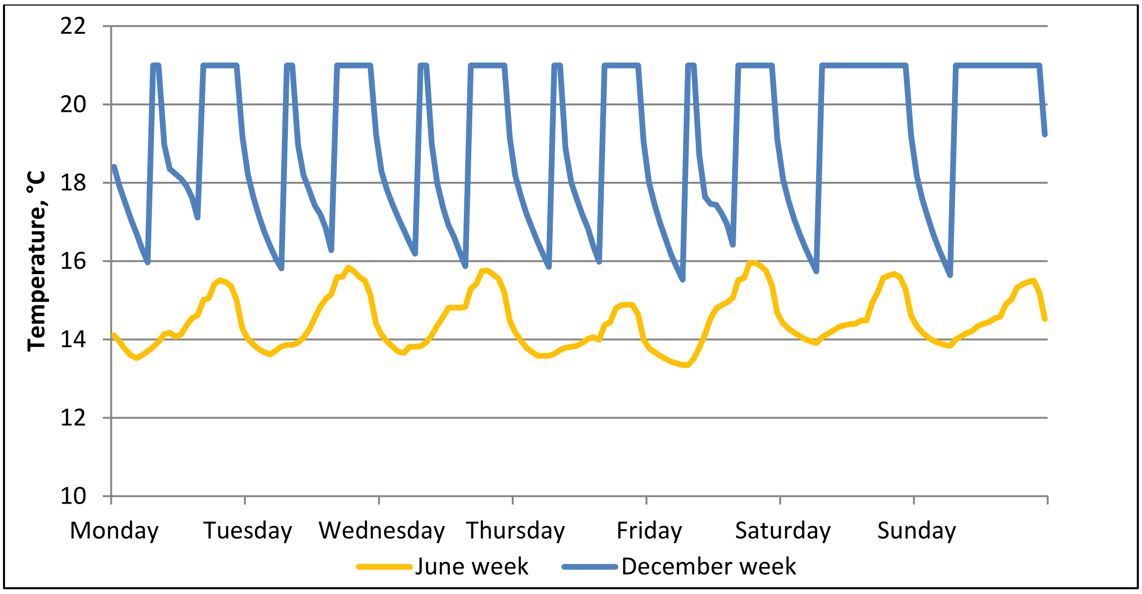


**Figure 4.22 Example living room temperature in CS4**

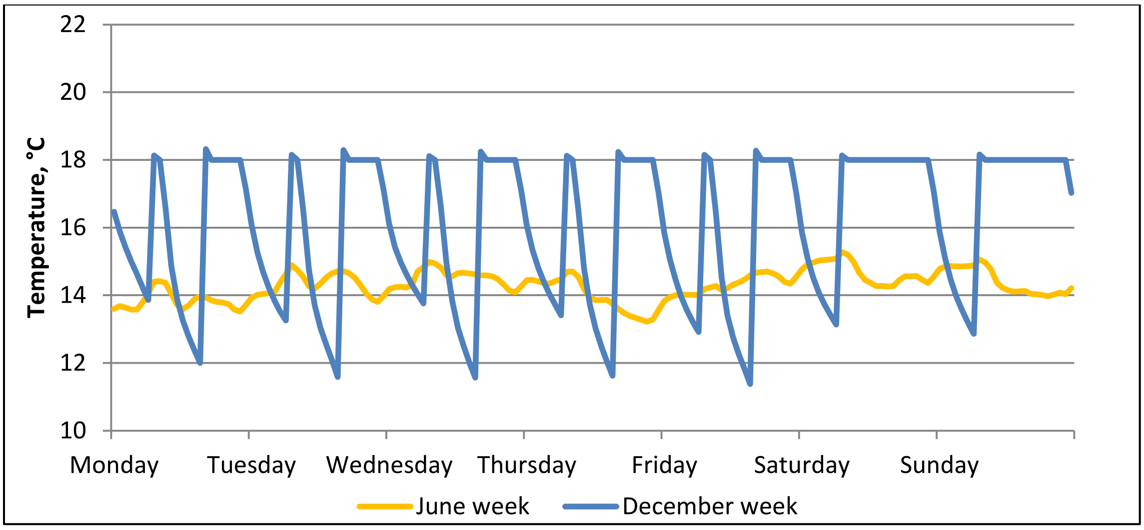


**Figure 4.23 Example 'rest of dwelling' temperature in CS4**

Whilst the retrofit measures have reduced the heat loss through the building fabric, these graphs of $T_i$ suggest the retrofit measures have also reduced the temperature variation over two particular short time periods. When looking at annual variation (Figure 4.24), the effect of the retrofit measures on the temperature profiles of the whole house again differ by assessment methodology. Across all three methodologies the increase in temperature is greatest in the heating season, which may be a response to the improved heat loss and improved effectiveness of the heating system.

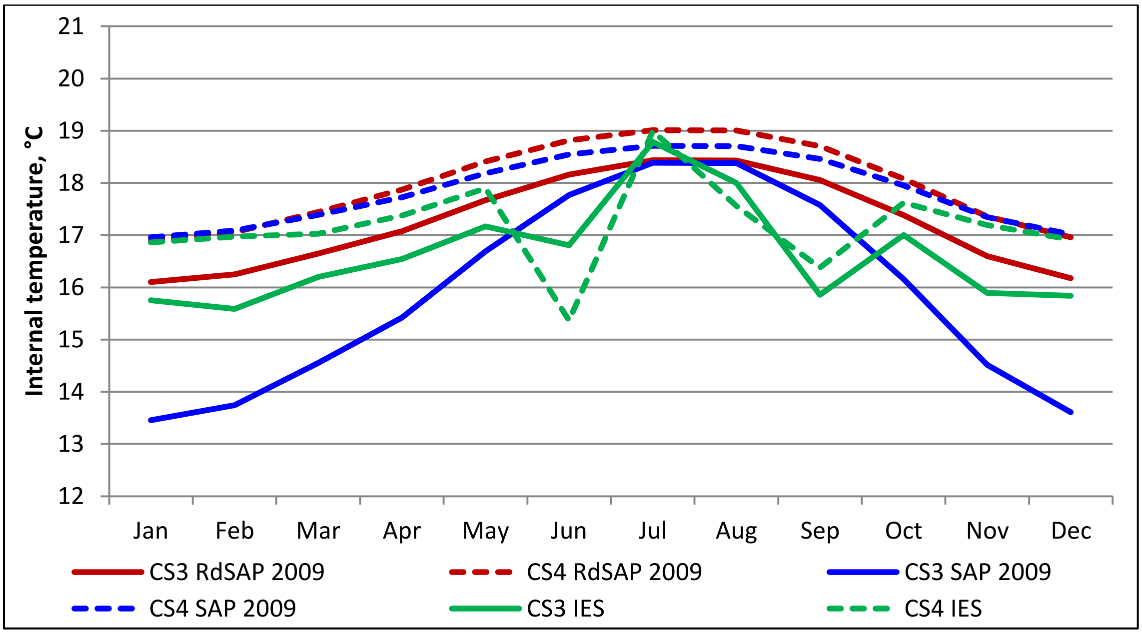


**Figure 4.24 Annual internal temperature by method**

The IES temperature profiles appear less stable than those of SAP and RdSAP 2009, due to the heating regime. The SAP heating regime was forced into IES, so in June when the heating is switched off, the average temperature in the dwelling drops to reflect the external temperature (Figure 4.25).

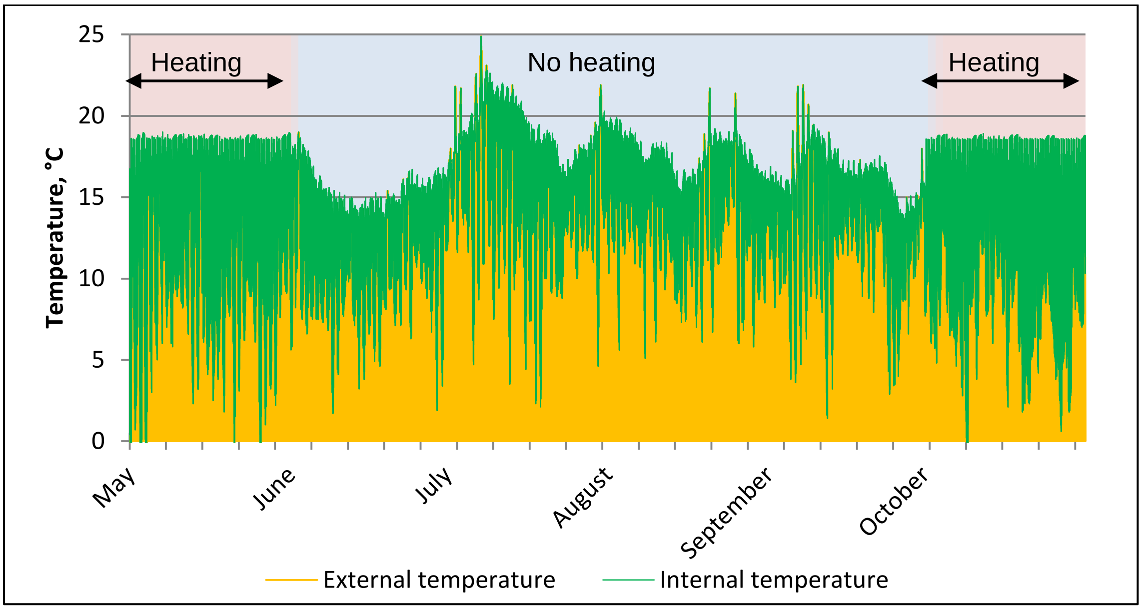


**Figure 4.25 Internal temperatures reflecting external temperature variability in CS4**

The temperature in the dwelling follows the external temperature until the heating is switched back on in October. If this fluctuating profile so dependent on external temperature was not there, it could be argued that all three methodologies would be in agreement over the internal temperatures in the retrofitted example throughout the year. As Figure 4.24 shows, the difference in calculated internal temperatures in CS4 is much less than in CS3. This could be taken as further evidence that the steady state models are not suited for existing dwellings of this construction type, and that they are more suited to dwellings with lower U-values where the conditions in the dwelling are more stable.

In summary, the retrofit measures as included in CS4 have reduced the temperature variation, and have reduced the summer internal temperatures. By putting insulation between the room and the thermal mass in the stone, these effects are contradictory to those expected, and warrant further consideration.

### *4.3.4 Thermal Mass*

Conventional thinking suggests that thermal mass acts to dampen temperature fluctuations and improve the thermal comfort of occupants, and that insulating between the room and the mass reduces this effect (The Concrete Centre, 2009). In Section 4.3.3 it was seen that this has not been the case in CS4.

The values in Table 4.7 highlight the difference the retrofit measures have had on the calculation within the SAP methodology for the thermal mass parameter (TMP), contrary to The Concrete Centre suggestions (2009); it must be remembered that for RdSAP 2009, a default is always assumed of 250kJ/m$^2$K. (For this section of discussion, the focus is purely on the steady-state methodologies, as the accredited model for dwellings. Discussion on the inclusion of thermal mass in IES will follow in Section 5.4.

**Table 4.7 Thermal Mass Parameter summary for CS3 and CS4**

| TMP (kJ/m$^2$K) | CS3 | CS4 |
|---|---|---|
| **RdSAP 2009 default** | 250 | 250 |
| ***RdSAP 2009 if assessed*** | *192* | *267* |
| **SAP 2009** | 197 | 332 |

The impacts of these values on the annual internal temperatures are shown in Figure 4.26. It is clear that the two significant effects on the calculated internal temperature are that of warming and stabilisation. Both SAP 2009 and RdSAP 2009 agree these findings for this particular case study.

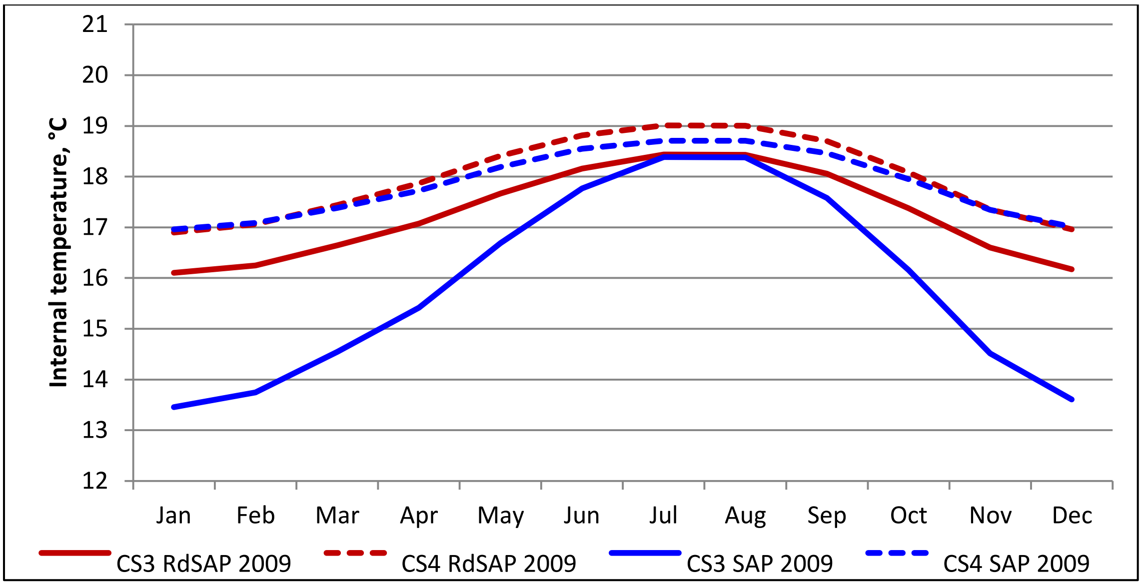


**Figure 4.26 Steady state internal temperature for CS3 and CS4**

An interesting feature is that in CS3, the largest temperature difference between methodologies is shown during the heating season, with near identical summer internal temperatures. Conversely, in CS4 the winter months are where the methodologies agree, with a difference (albeit slight) during the summer.

*Pre*-retrofit, SAP 2009 suggests cooler indoor temperatures than RdSAP 2009 across the year. *Post*-retrofit, SAP 2009 suggests cooler indoor temperatures than RdSAP 2009 only in the summer months. As Table 4.7 highlighted, the difference in the TMP used in the calculation changes significantly between the two case studies. With the TMP set at 250kJ/m$^2$K in RdSAP 2009, the SAP 2009 value is lower in CS3 and higher in CS4. Having only these two points however does not lead to a solid conclusion. Therefore, additional calculations have been done using the two case studies, applying varying levels of thermal mass to the SAP 2009 calculation, and forcing RdSAP 2009 to do the same. Using the definitions of low, medium and high thermal mass within the SAP documentation, the following values were used in the calculations: low – 100 kJ/m$^2$K; medium - 250 kJ/m$^2$K; and high - 450 kJ/m$^2$K. The resulting internal temperature profiles have been plotted in Figure 4.27, highlighting the effect that varying levels of Thermal Mass Parameter have on the SAP calculation.

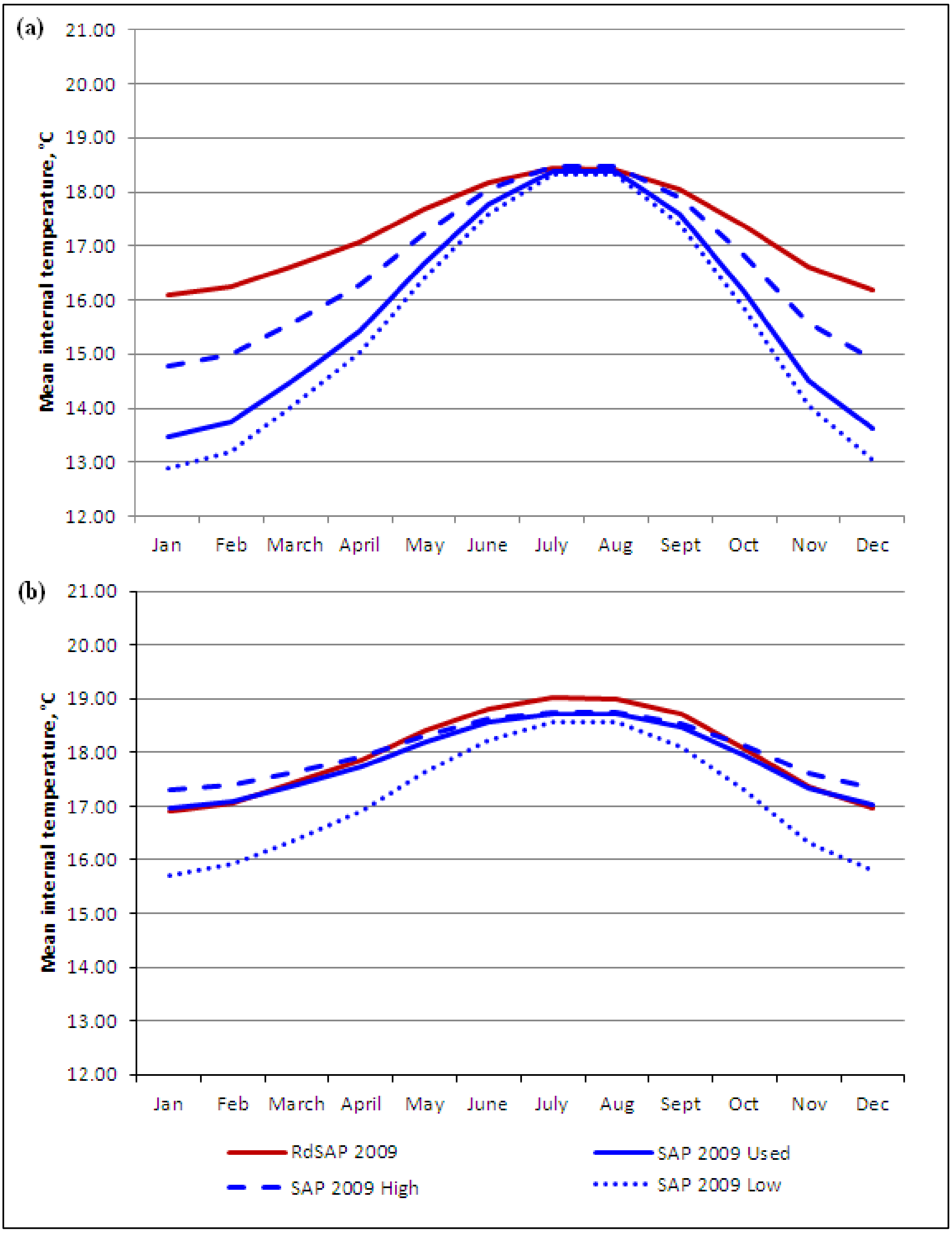


**Figure 4.27 TMP variation effect on internal temperature in (a) CS3 and (b) CS4**

In SAP 2009, the lowest TMP in both case studies predicts the lowest internal temperatures, with the highest TMP predicting the highest internal temperatures. The temperatures across the year in both case studies are less variable the higher the TMP. The difference between the pre- and post-retrofit case studies is seen predominantly in the winter months, where the post-retrofit dwelling experiences warmer internal temperatures in all cases.

As RdSAP 2009 uses a ‘medium’ value of TMP, it would be expected that the RdSAP 2009 result would sit somewhere between the high and low TMP results from SAP 2009, if the rest of the calculation were identical. In neither case study is this seen. Pre-retrofit, the RdSAP 2009 internal temperatures are above any calculated by SAP 2009 throughout the year. Post-retrofit the same is seen during the warmer months, with the winter temperatures from RdSAP 2009 matching those of the original SAP 2009 calculation. It is therefore suggested that further work is either needed into the inclusion of thermal mass within the steady state calculation methodology; into the default thermal mass used within RdSAP; or into collecting data on the thermal mass of traditional wall constructions to better inform the calculations.

By studying CS3 and CS4 the ability of SAP, RdSAP and IES to predict savings from sustainable refurbishment measures have been challenged. The dwelling utilised its existing structure and maintained its character, but dramatically reduced the emissions, and improved the costs and thermal comfort for the occupants.

## 4.4 Case Study 5 – Semi-detached bungalow

The dwelling used for CS5 has a mixture of the old (thick solid stone walls) and the new (double glazing), has challenges with respect to potential savings available as it is off the mains grid, has an extension added in the 1980s, and is a semi-detached bungalow. The focus here is on the dwelling type and heat loss areas associated with being an old bungalow, rather than refurbishment savings, as was the focus of the previous case studies.

### *4.4.1 Draught-proofing*

Within the steady-state methodologies, the assessor must enter a factor for the level of draught-proofing in the dwelling. In SAP 2009, this is entered as an integer representing the percentage of windows and doors draught-stripped. In RdSAP 2009, this integer is assumed as the percentage of windows classed as 'multiple glazing' – whether double, triple, or secondary. Doors are assumed to not be draught-stripped. It is questionable what impact this integer has on the final energy requirement, and for that reason a number of iterations have been carried out to ascertain the magnitude of this effect. This is an important consideration if SAP or RdSAP 2009 were to be used for refurbishment calculations as draught-proofing is typically seen as one of the cheapest and easiest options to install. If the calculation determines very little saving, the homeowner may be reluctant to apply the measure, but it is well known that air movement affects thermal comfort, and that draught-proofing can improve the thermal comfort of the occupants in a "leaky" building during cold weather (CIBSE, 2006). The results of the iterations are shown in Figure 4.28.

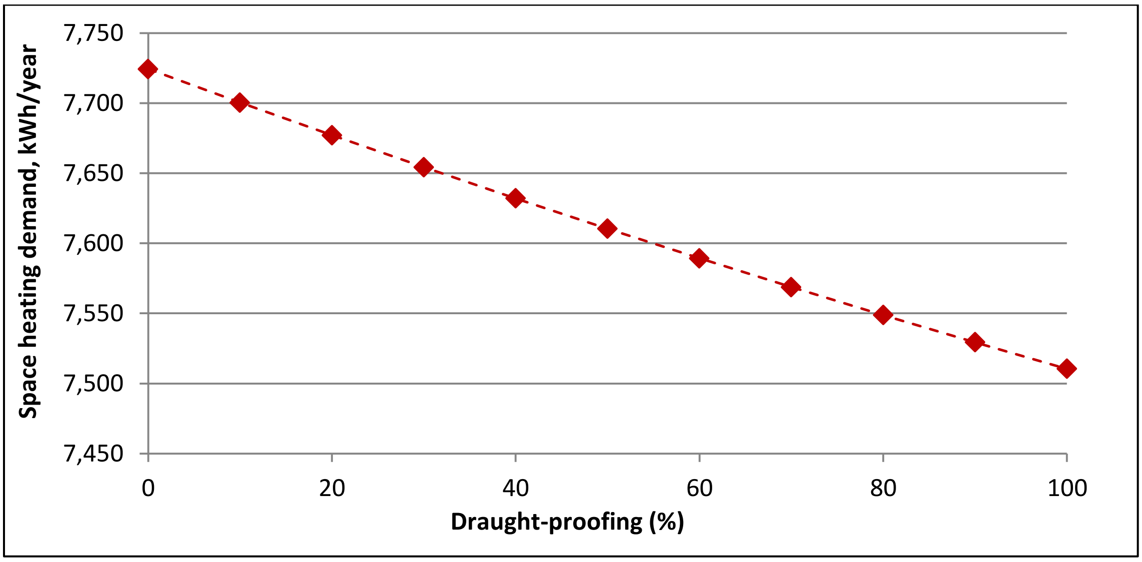


**Figure 4.28 How draught-proofing impacts on end-results in RdSAP 2009**

The first point to note in Figure 4.28 is that of the scale. The difference between zero draught-proofing and full draught-proofing is 214 kWh/year in RdSAP 2009, but over a initial demand of 7,724 kWh/year, this equates to a cost difference of just £16 over a year between worst and best case scenario. Anecdotal evidence from the occupant suggests that upon the implementation of draught-proofing of the doors, a minor improvement in the thermal comfort was experienced, noticeable through a warmer wooden floor surface, but no change was made to the heating system. This would agree with the estimation of insignificant change through the calculation methodologies.

Also investigated along with the space heating requirement was the EPC result – which unsurprisingly remained unchanged across all variants with such a low cost difference. In addition, the effective air change rate was recorded in each case, and reduced by just $0.01m^3/h/m^2$ for every 10% increase in draught proofing.

These small differences can be explained by looking at the section of calculation in which draught-proofing is included within SAP and RdSAP 2009 (Figure 4.29).

**2. Ventilation rate**

| | main heating | | secondary heating | | other | | total | | m³ per hour | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of chimneys | | + | | + | | = | | × 40 = | | (6a) |
| Number of open flues | | + | | + | | = | | × 20 = | | (6b) |
| Number of intermittent fans | | | | | | | | × 10 = | | (7a) |
| Number of passive vents | | | | | | | | × 10 = | | (7b) |
| Number of flueless gas fires | | | | | | | | × 40 = | | (7c) |
| | | | | | | | | | Air changes per hour | |
| Infiltration due to chimneys, flues, fans, PSVs | (6a)+(6b)+(7a)+(7b)+(7c) = | | | | | | | ÷ (5) = | | (8) |
| *If a pressurisation test has been carried out or is intended, proceed to (17), otherwise continue from (9) to (16)* | | | | | | | | | | |
| Number of storeys in the dwelling ($n_s$) | | | | | | | | | | (9) |
| Additional infiltration | | | | | | | [(9) – 1] × 0.1 = | | | (10) |
| Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction* *if both types of wall are present, use the value corresponding to the greater wall area (after deducting areas of openings); if equal use 0.35* | | | | | | | | | | (11) |
| If suspended wooden floor, *enter 0.2 (unsealed) or 0.1 (sealed)*, else enter 0 | | | | | | | | | | (12) |
| If no draught lobby, enter 0.05, else enter 0 | | | | | | | | | | (13) |
| Percentage of windows and doors draught stripped | | | | | | | | | | (14) |
| Window infiltration | | | | | | | 0.25 - [0.2 × (14) ÷ 100] = | | | (15) |
| Infiltration rate | | | | | | | (8) + (10) + (11) + (12) + (13) + (15) = | | | (16) |

**Figure 4.29 Calculation towards infiltration rate in SAP 2009 v9.90, p152 (BRE 2010)**

The level of draught-proofing is entered at box (14) as an integer, so when added to the other sources of infiltration – chimneys, fans, vents, sheltered sides etc. – the difference will be minimal as box (15) will only change between 0.25 with no draught-proofing and 0.05 with 100% draught-proofing. When fed through the calculation to incorporate the infiltration rate, wind speed and any mechanical ventilation systems, for CS5 the difference in effective air change rate is only between 0.73 with no draught-proofing and 0.63 with 100% draught-proofing.

In IES, an infiltration rate was used according to CIBSE Guide A, Table 4.21 ‘Empirical values for air infiltration rate due to air infiltration for rooms in buildings on normally-exposed site in winter – dwellings; partial exposure’. The Guide allows you to ascertain the average and peak infiltration rate for a dwelling depending on the type, number of storeys, and level of air permeability. For CS5, the average infiltration rate for a leaky single storey dwelling is 1.15 ach, this figure was used in IES. This figure is most similar to that calculated by SAP 2009. Similarly to the steady-state methodologies, variations in infiltration have been entered into IES to ascertain final space heating demand; these are shown in Figure 4.30 below. As 1.15 ach in Guide A is the maximum, worst case dwelling, values for infiltration better than this have been used, down to 0.85 ach, the lowest rate of air changes from the steady state models.

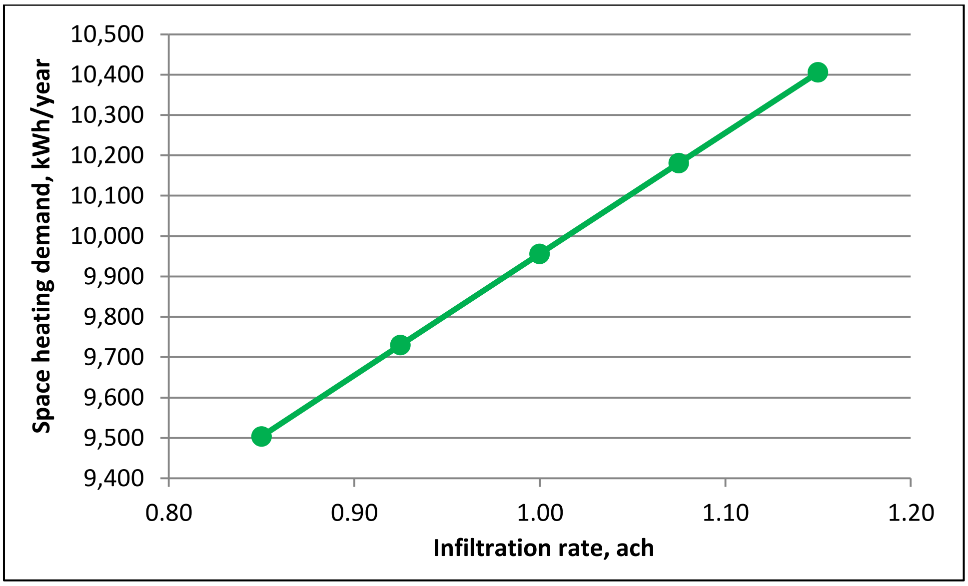


**Figure 4.30 Infiltration effect on space heating demand, IES**

It is immediately obvious that not only is IES estimating a larger heating demand than the steady state methodologies to begin with, but changes in infiltration rate have a more significant impact on the energy demand for space heating. This introduces the question of whether it is the infiltration rate, rather than the level of draught-proofing entered into SAP and RdSAP 2009 that is important for the calculation. Iterations on infiltration rate, matching that of IES have therefore also been carried out, the results shown in Figure 4.31.

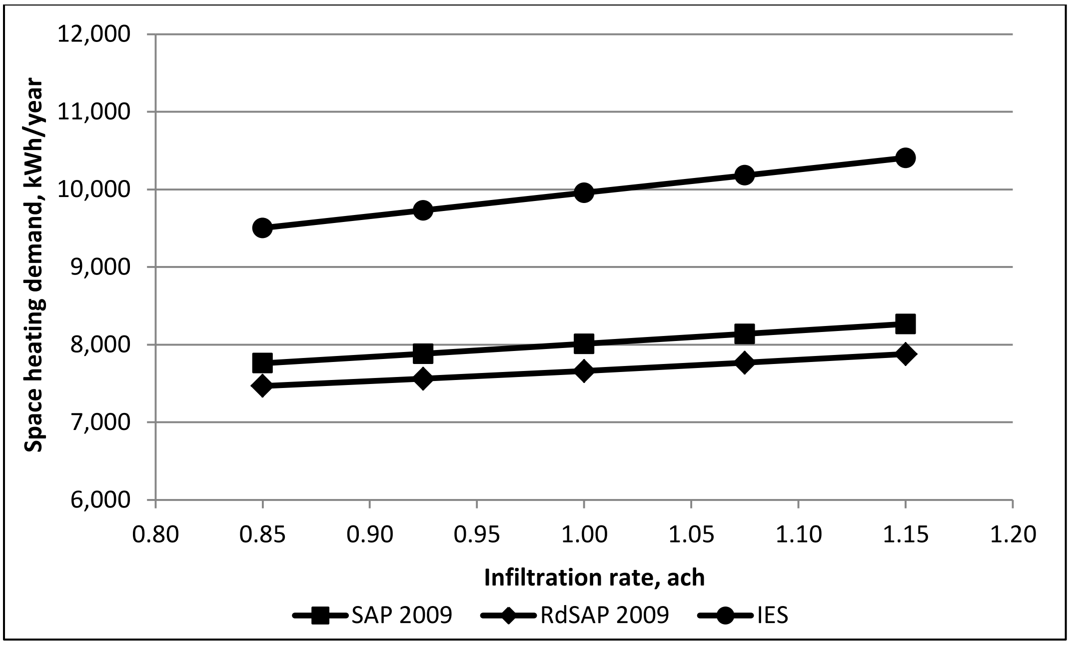


**Figure 4.31 Infiltration effects on all three methodologies**

From Figure 4.31 it is seen that it is the infiltration rate, *not* the draught-proofing that effects the space heating demand, and therefore the overall energy performance estimated by the methodologies. There are many aspects of a dwelling that impact on the infiltration rate, as well as just the draught-proofing, as seen from the calculation laid out in Figure 4.29.

An additional variable affecting the infiltration rate is that of the presence of a draught lobby. It is now explored whether the presence of a draught lobby has a similar negligible effect on the space heating demand.

### *4.4.2 The 'draught lobby'*

The SAP 2009 methodology has a strict definition of a draught-lobby:

> "A draught lobby is an arrangement of two doors that forms an airlock on the main entrance to the dwelling. To be included, the enclosed space should be at least 2m$^2$ (floor area), it should open into a circulation area, and the door arrangement should be such that a person with a push-chair or similar is able to close the outer door before opening the inner door."
>
> (BRE, 2010)

In RdSAP 2009, Table S5 gives a number of ventilation parameters to be used; this includes the presence of a draught lobby. If the dwelling is a flat or maisonette, it is assumed a draught lobby is present whether the corridor is heated or unheated. In a house of bungalow, as per CS5, it is always assumed there is no draught lobby.

This final case study dwelling has a small area by the main door (Figure 4.32, 'Entrance') that acts as a draught lobby, but cannot be counted as such as it does not meet any of the three criteria in the definition within SAP 2009, and as a bungalow is restricted to assuming no draught lobby within RdSAP 2009.

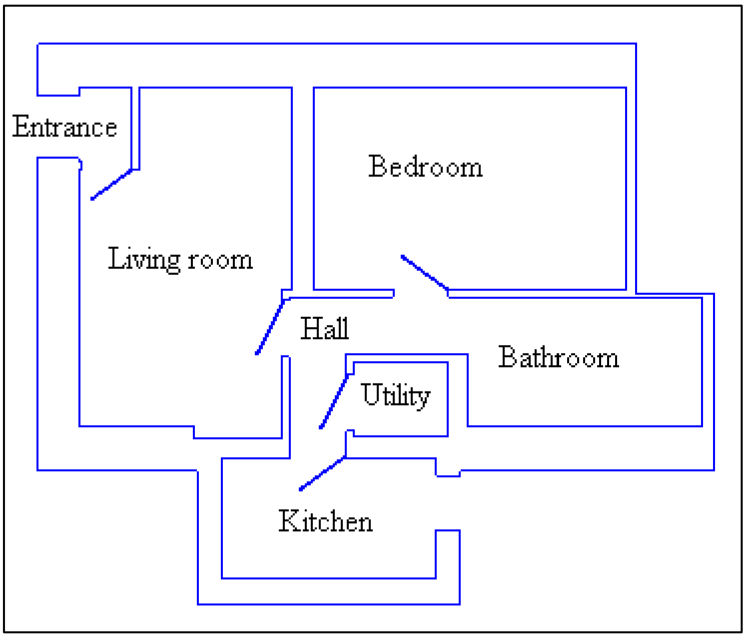


**Figure 4.32 Floor plan of CS5**

Anecdotal evidence from the occupant indicates the entrance is the coldest part of the house, despite new draught-proofing being recently added to the door. If this is the case, then this small room whilst not meeting the strict definition and therefore not being included in the calculation, does aid in keeping the living room warmer than it would be otherwise. Therefore, the SAP and RdSAP 2009 calculations have been repeated with and without a draught lobby, to investigate the level of effect this has on the dwelling annual average temperature and space heating demand, according to the calculation.

**Table 4.8 Impact of draught lobby assumptions on calculations**

| SAP 2009 | With draught lobby | Without draught lobby |
|---|---|---|
| Average internal temperature (°C) | 17.30 | 17.28 |
| Space heating demand (kWh/year) | 8,222 | 8,308 |
| SAP rating | 38.28 (F) | 37.89 (F) |
| **RdSAP 2009** | **With draught lobby** | **Without draught lobby** |
| Average internal temperature (°C) | 18.16 | 18.15 |
| Space heating demand (kWh/year) | 7,412 | 7,469 |
| SAP rating | 42.00 (E) | 41.71 (E) |

As Table 4.8 shows, the 'introduction' of a draught lobby acts to improve the internal temperature, reduce the demand for space heating, and improve the SAP rating, albeit marginally. It is proposed that if a dwelling's energy performance rating was within a few decimal places of a different rating band, that this may be an issue with respect to the ability of either of the steady state methodologies to represent the thermal situation within the dwelling.

The dynamic model has not been recalculated, as the methodology includes the nature of each room, and recognises that the 'Entrance' is a space connected by an opening to the external environment. If the additional module with IES title MacroFlo had been used, the air flow between the entrance and the living room could also have been specified.

### *4.4.3 Heat loss*

In section 4.2 the effect of a large heat loss area from a detached house was discussed. The areas of heat loss associated with CS2 and CS5 are shown in Table 4.9, and it is clear that despite the large size of CS2, there is a greater level of heat loss associated with CS5. Despite the dwelling being semi-detached thereby having less heat loss wall than a detached property, the nature of a bungalow leads there to be not only heat loss through the floor, but also the roof. From the heat loss area understanding from Table 4.9, it is suggested that the high energy requirement for the dwelling is therefore not only attributed to the building fabric, but also the type of dwelling.

**Table 4.9 Heat loss area comparison**

| | **CS2** | **CS5** |
|---|---|---|
| **Total heat loss area ($m^2$)** | 596.14 | 160.38 |
| **Total floor area ($m^2$)** | 361.42 | 47.97 |
| **Heat loss area per floor area** | **1.65** | **3.34** |

## 4.5 Summary

Chapter 4 has focused on individual elements of the SAP and RdSAP 2009 methodologies, analysing individual case studies. The following chapter brings these results together, to ascertain any trends in results across all 5 case studies, and to discuss which aspects of the calculation methodologies, if any, warrant further investigation and improvement by the BRE and Building Standards.

# CHAPTER 5 – MODEL ANALYSIS

## 5.1 Energy Requirement

Across the findings discussed in Chapter 4, it was found that space heating was the most significant user of energy in the dwellings. Therefore Chapter 5 uses space heating demand and space heating requirement to discuss the differences between methodologies, except where alternative specific sections of the methodologies are analysed. Figure 5.1 therefore provides a starting point for which all following analysis can refer back to.

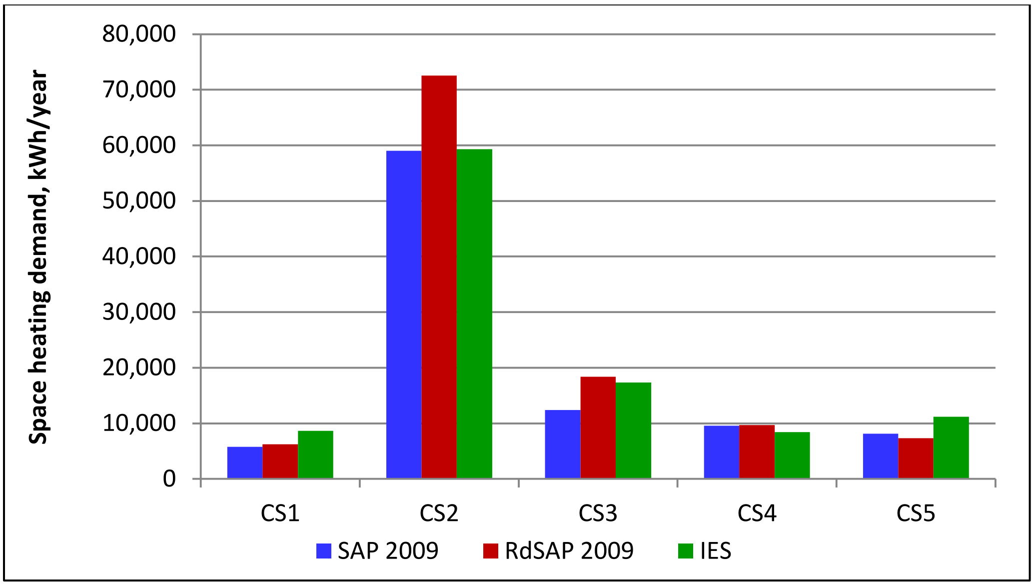


**Figure 5.1 Annual space heating demand for each case study according to each calculation methodology**

For these five dwellings there is no clear trend: no methodology consistently estimates highest or lowest demand. However, in 4 out of 5 cases, IES and RdSAP 2009 predict higher space heating demand than SAP 2009. Throughout the latter sections of this chapter, as parameters within the methodologies are analysed, reasons for this will be explored.

The ‘Future of Heating Strategy’ for the UK (DECC, 2012) claims that on average, 79% of home energy use is for space heating and domestic hot water (DHW), across the residential stock. This figure matches that given by the Energy Consumption in the UK domestic data tables, which also show a steady decline in this figure from 86% in 1970 (DECC, 2012). Figure 5.2 shows the split of energy use across these case study dwellings according to RdSAP 2009 (as the accredited methodology), and shows that in all five case studies the proportion of space heating and DHW is significantly higher than in the DECC strategy report.

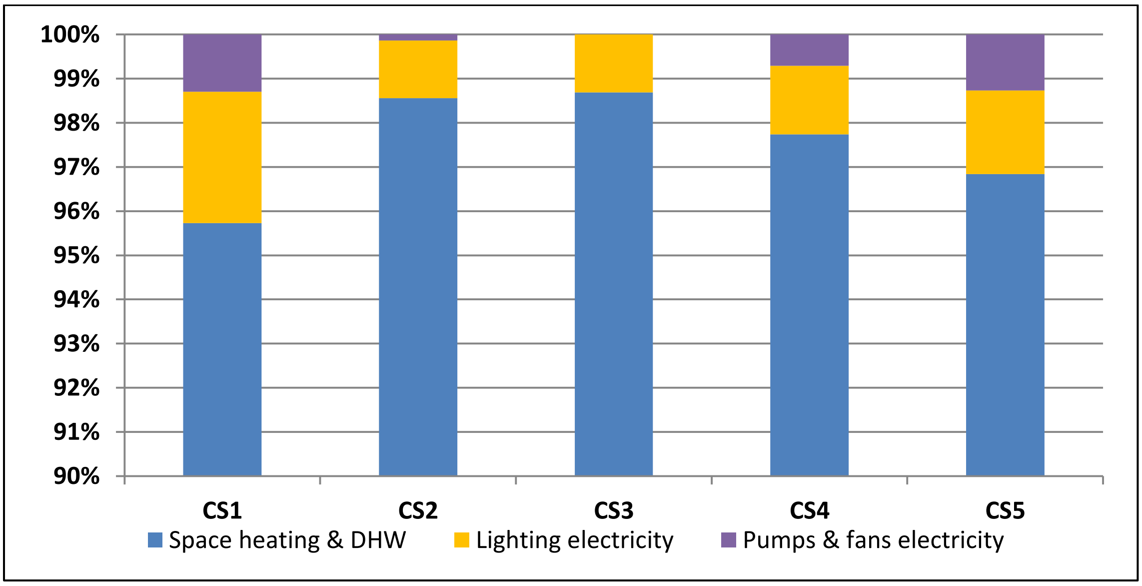


**Figure 5.2 Proportion of energy use, from RdSAP 2009**

The lowest space heating and DHW proportion is CS1, at just under 96%; the highest is CS3 at just under 99%, far higher than the UK national average.

The UK Energy Consumption figures additionally suggest that an average 18% of a household's energy is used for DHW. Figure 5.2 can be broken down to include DHW as a separate variable, shown in Figure 5.3 (note the different scales used).

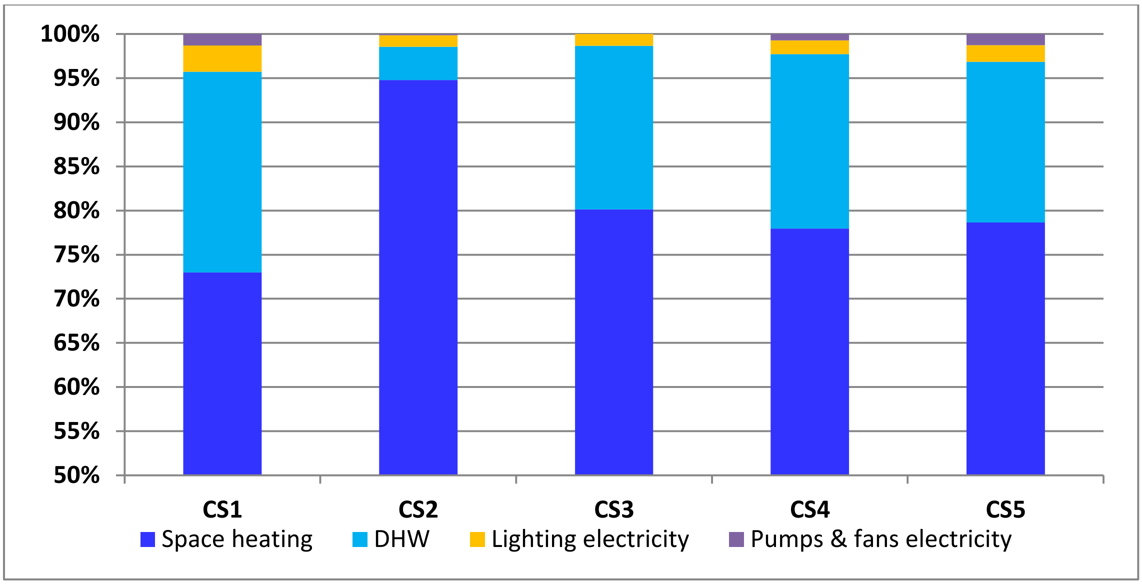


**Figure 5.3 Proportion of energy demand, showing DHW, from RdSAP 2009**

This shows that in all but CS2, the DHW uses between 18 and 23% of the dwelling total energy as estimated by RdSAP 2009, matching that of the UK average. In CS2, the predicted space heating demand is so large that the DHW proportion is only 4% (with pumps and fans at just 0.01%). In CS3 there is no electricity associated with pumps and fans, due to there being no central heating system.

As the two previous charts show space heating demand rather than requirement, any difference between CS3 and CS4 is down to the fabric and lighting improvements. While the total energy demand for space heating reduces by 59% post-retrofit, the DHW and lighting energy also reduce by 55% and 50% respectively, with a small energy increase for pumps and fans associated with the introduction of the central heating system. Therefore the proportion of space heating demand with respect to total energy demand stays similar across the comparison of pre- and post-retrofit: in CS3, space heating accounts for 80% of total predicted demand, while in CS4 this figure is 78%.

Figure 5.2 and Figure 5.3 show the proportions of energy for all case studies from the RdSAP 2009 methodology only. The following charts identify the differences between methodologies used, and show the fuel *requirement*, and therefore include the assumptions of the methodologies towards the heating and DHW systems.

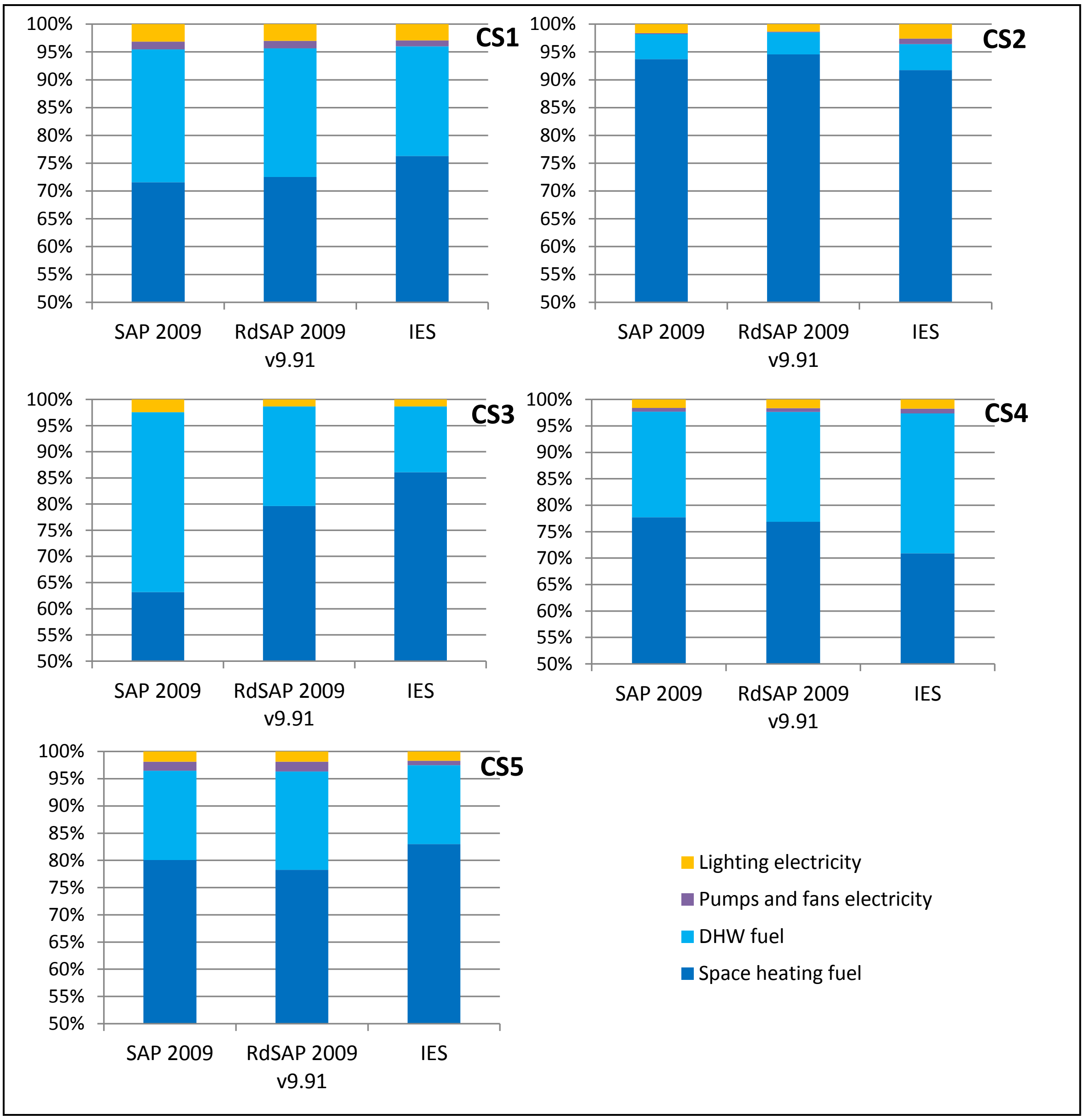


**Figure 5.4 Comparison of methodology's estimation of energy requirement**

In Figure 5.4, the proportion of final energy requirement is displayed, identifying the differences between methodologies for all five case studies. It should be noted that as the calculation towards DHW is identical in both SAP 2009 and RdSAP 2009, any difference in the above figure is due to the variation in the other energy consumer's contribution between the methodologies.

There is little difference between the methodologies for CS1, although IES puts slightly greater significance on space heating than the steady state models. In CS2, there is similarly little difference due to the large space heating requirement, although it is observed that IES puts the least significance on space heating, with a greater proportion of energy consumption for pumps, fans, and lighting than either of the steady state models, due to the nature of the lighting calculations (see Section 5.8).

The results for CS3 show similar trends to that of CS1 with respect to the methodologies; with the difference in space heating energy proportion due to the difference in assumptions towards the space heating systems between SAP 2009 and RdSAP 2009 as outlined in Section 4.3.1. In CS4, both steady state methodologies estimate similar proportions of energy, but the reduction in space heating requirement is of more significance in IES.

In CS5, all the models are in approximate agreement, although IES suggests the highest space heating and lowest DHW consumption as a proportion of total energy. This reflects with the trend that IES predicts highest space heating requirement.

In three of the five case studies (CS1, CS3, CS5) IES has the highest space heating contribution while SAP 2009 has the lowest space heating contribution. RdSAP 2009 has the highest space heating contribution in CS2, and similar in CS4. It is therefore suggested that no conclusion with respect to a single methodology over another, can be drawn from assessing these five case studies only. It can however be concluded that space heating is by far the largest contributor to total energy consumption in these dwellings.

## 5.2 Energy Cost

For many if not most occupants, the cost of staying warm through the winter can be the primary concern with respect to the cost of running a home. This section will briefly look at the methodologies' ability in calculating costs for a home. It is worth repeating that the methodologies are prediction tools only, and will never be able to accurately forecast real-life energy cost, as the occupants are responsible for the energy usage not predicted within the calculation, and this will change dwelling by dwelling. Additionally, each methodology is calculated for average climate, therefore costs experienced by homeowners for space heating could also differ from that suggested by the EPC depending on the severity of a particular winter.

Figure 5.5 gives the cost for space heating for each case study, and it is immediately obvious that there is a connection between space heating demand (Figure 5.1) and space heating cost.  The cost is calculated simply by including the efficiency of the heating system. Each case study has different system efficiencies, but as was seen in Section 4.3.1, the efficiency of the system between CS3 and CS4 actually reduces, but as the demand reduces, the cost still reduces despite the poorer system efficiency.  This implies that both the energy demand and efficiency are important when attempting to reduce space heating cost.

As seen with space heating demand, there is little trend across the five case studies as to one particular methodology predicting highest or lowest cost.  This may be due to the varying system efficiencies.  If the calculations were repeated with the same heating system, a trend may be experienced.  However, this approach is inappropriate, as heating systems are sized to a particular dwelling, as seen with CS2 requiring two large boilers.  While a single efficiency may be input, the research here has been based on real-life rather than theoretical approaches.

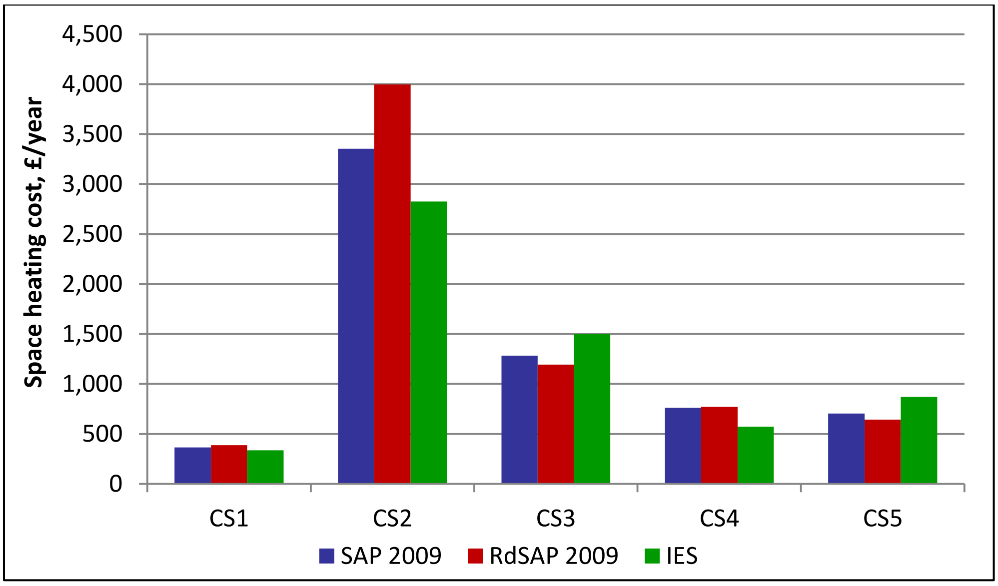


**Figure 5.5 Total space heating cost by each methodology**

As the final energy demand mirrors that of the space heating, Figure 5.5 doesn't tell us anything of significance regarding the methodology's estimation of total energy cost in addition to the previous analysis of energy requirement, except in the case of CS3.  The assumptions made towards heating systems lead to energy costs that do not shadow the energy consumption (Figure 5.6).

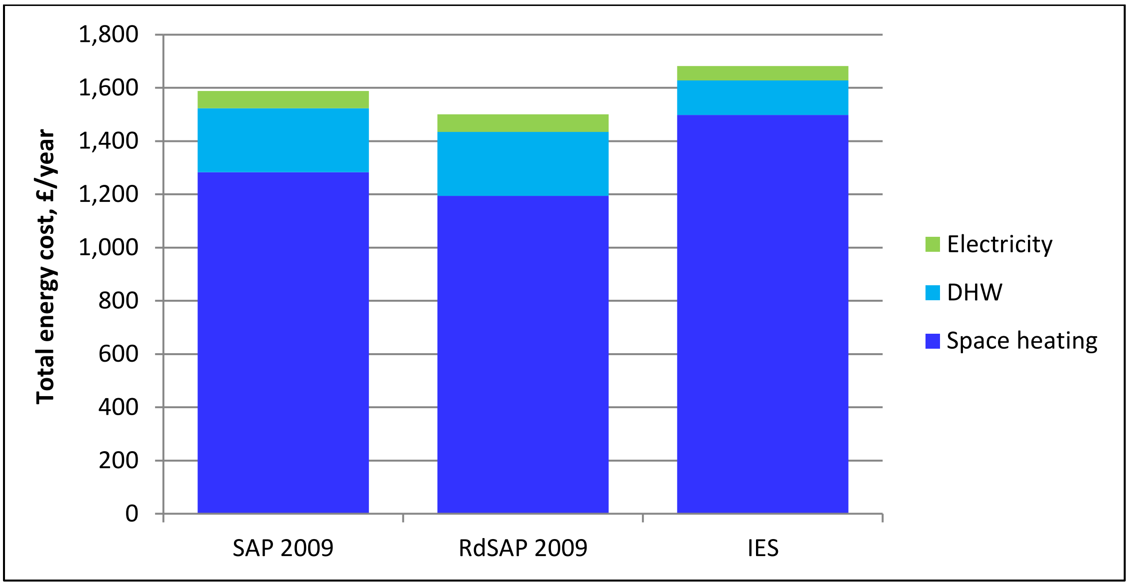


**Figure 5.6 Breakdown of estimated costs for CS3 by methodology**

The differences in heating assumptions described in Table 4.5 lead to lower costs estimated by RdSAP 2009, despite 90% of the heating coming from a lower efficiency source. This is down to the varying costs of fuel used by the SAP calculation: coal at 2.97p/kWh and electricity at 11.46p/kWh.

By studying energy costs, the householder can assess whether savings are more likely from a higher efficiency appliance, or changing the fuel used. In many cases the latter is not possible, for example rural dwellings off the gas grid are restricted to more expensive fuels such as electricity, biomass or LPG. The breakdown of cost for space heating and hot water is given on an EPC, but the explanation behind the calculations is missing, questioning the efficacy of the format of information given to householders. If the ‘rainbow rating’ is the first section of the EPC noticed by the majority – certainly it is the SAP rating that is mandatory on advertisements for dwellings for sale or let – the SAP rating should also be considered as the final result of each methodology.

## 5.3 SAP Rating

### *5.3.1 Energy Performance Certificates*

In Scotland, it is a legal requirement to display the SAP rating of a property in an advert, and many will be familiar with the sight of the ‘rainbow rating’. The UK Government has proposed a minimum energy standard, proposing that from 2018, a dwelling must be at least an E-rating, before it can be sold or let (DECC, 2013). The research in this project suggests that, firstly, it may it be difficult to reach such a rating for dwellings such as those analysed in this project, with severe implications for the owners and landlords of traditional property in Scotland. Secondly, that the result is reliant on the calculation and assumptions used, in addition to the assessor’s ability to understand the dwelling. Figure 5.7 shows the difference in rating dependent on methodology used, and the difficulty that could arise if a dwelling were assessed to be on the boundary between two ratings: in only CS1 and CS3 do all three methodologies agree on a SAP rating.

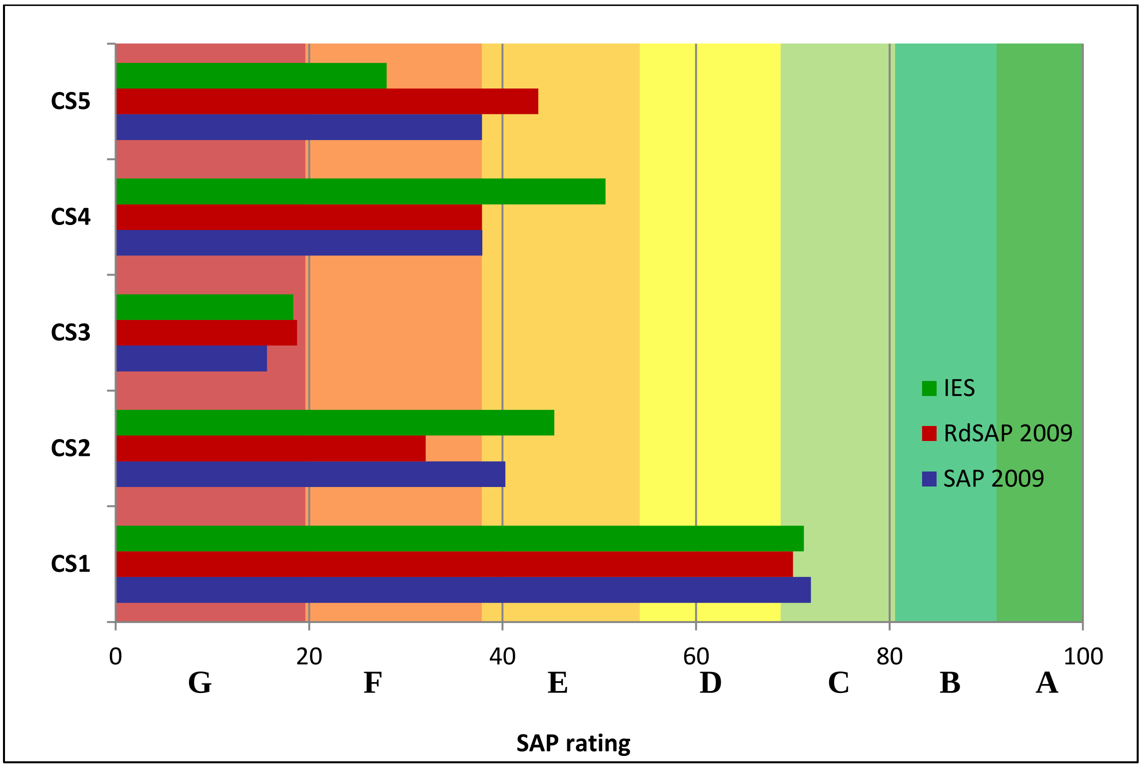


**Figure 5.7 EPC rating estimated by each methodology**

The results also show that whether the dwelling is seen as inefficient very much depends on the type of dwelling. The tenement flat (CS1) gets a rating better than the UK average, similar to new-build properties, and could be seen as energy efficient, despite the solid un-insulated walls and single glazing.

Whilst not a key component of this research project, the improvements made to CS3 have improved the SAP rating from a G in all three methodologies, to an F in the steady state models, and an E in the dynamic model. In this case therefore, additional work would be required beyond that already completed, in order to be able to sell or let the dwelling beyond 2018, as the steady state methodologies are the accredited routes used by official assessors. Additional work could be costly and primarily run on low or zero carbon technology, as the building fabric has already been insulated and improved.

### *5.3.2 Different assessors*

Ratings given to CS1 and CS5 are available from energy assessments carried out prior to the purchase of CS1 and letting of CS5 by accredited assessors, therefore comparisons can be made with a second assessment, as a small number of inputs in RdSAP are based on assessor interpretation.

The assessment for CS1 gave the dwelling a D rating, with a value of 63. The assessment carried out for this research calculates a rating of C with a value of 70. This differs for two reasons. Firstly, since the property sale the boiler used for space heating and DHW has been replaced, providing an increase in efficiency from an old non-condensing boiler to a new condensing combi boiler, with an efficiency of 88.9%. Despite the relatively low space heating demand, such an improvement in the delivery system will have impacted on the end result, and whilst not the aim of this research, provides a good example of an energy retrofit measure. The second reason for the difference in assessments is that close examination of the EPC shows that the assessor has included an assumption that there is no dwelling below the dwelling in question, and therefore has applied heat loss to the floor area. This is a prime example of how assessors can differ, as through discussion with the homeowner it was determined that there *is* a flat directly below the flat in question; therefore heat loss is not included, leading to a 65$m^2$ difference in assessed heat loss area between the two assessments.

The assessment for CS5 gave the dwelling a G rating, with a value of 19. In this case, the full EPC report was not available, and it has been therefore unable to provide suggestions as to why this research provides a higher rating. It may be that the original assessor assumed a default level of loft insulation in comparison to the 240mm foil-backed loft insulation observed for this research. Alternatively, there may be slight differences in dimensions between the original assessment and that used in this research. As previously noted in Section 4.4.3, the semi-detached nature of this case study provides it with significant heat loss area, and a small change in external dimensions may have impacted on the internal dimensions using the RdSAP methodology for transforming external dimensions to internal dimensions.

The transformation from external to internal dimensions is based on the assumed wall thickness given by RdSAP, but if the wall thickness in the dwelling differs from that, there will be a discrepancy between an assessment using internal dimensions and an assessment using external dimensions.

### *5.3.3 RdSAP 2005*

The EPC assessments for both CS1 and CS5 were carried out using RdSAP 2005, the previous methodology. This was introduced in 2005 and used until 2010 when the 2009 edition was included in the Building Standards. The 2005 methodology (v9.80 and v9.81) used an annual steady state calculation. This therefore assumed single average values for a year, and could not take account of seasonal variation in heating demand, external temperature and solar gain, thus there is inevitably a difference between an annual estimation and monthly estimation. The two dwellings in question have been assessed under RdSAP 2005, the results shown in Table 5.1.

**Table 5.1 Comparison of RdSAP methodologies**

| | RdSAP 2005 v9.81 | | RdSAP 2009 v.9.91 | |
|---|---|---|---|---|
| | **SAP value** | **SAP rating** | **SAP value** | **SAP rating** |
| **CS1** | 63 | D | 70 | C |
| **CS5** | 19 | G | 42 | E |

The RdSAP 2009 technical guidance does provide assessors with a guide to the relationship between the two methodologies (Figure 5.8). From this it can be seen that for CS1 a 2009 rating of approximately 60 may have been expected. The improvement to 70 may therefore be solely due to the change in calculation and the improved boiler since the original assessment. To ascertain which of these reasons may be most likely, the dwelling was assessed in RdSAP 2005 with the improved boiler, and received a rating of 74. When looking up 74 in RdSAP 2005, the guidance expects a value of around 70 in the 2009 methodology. This suggests the improvement is due to the change in calculation methodology between the 2005 and 2009 editions of the RdSAP methodology.

**Table 15 : Relationship between SAP 2005 ratings and SAP 2009 ratings**

Where possible, SAP ratings previously calculated using SAP 2005 should be re-calculated using SAP 2009. The table indicates typical differences between the ratings.

| SAP 2005 | SAP 2009 for main heating fuel as: | | | | | |
|---|---|---|---|---|---|---|
| | **Mains gas** | **LPG** | **Oil** | **Electricity** | **Solid mineral** | **Biomass** |
| **1** | 1 | 10 | 1 | 6 | 12 | 9 |
| **10** | 9 | 20 | 9 | 16 | 21 | 18 |
| **20** | 19 | 31 | 19 | 26 | 31 | 28 |
| **30** | 29 | 41 | 29 | 37 | 41 | 37 |
| **40** | 39 | 50 | 39 | 46 | 50 | 47 |
| **50** | 48 | 59 | 50 | 56 | 59 | 56 |
| **60** | 58 | 68 | 60 | 65 | 68 | 65 |
| **70** | 67 | 76 | 70 | 74 | 77 | 74 |
| **80** | 76 | 84 | 80 | 82 | 85 | 83 |
| **90** | 85 | 92 | 90 | 91 | 93 | 92 |
| **100** | 94 | 99 | 100 | 99 | 100 | 100 |

**Figure 5.8 The typical difference between ratings calculated using the 2005 and 2009 methodologies. Table 15 in (BRE, 2010).**

The results for CS5 appear to be vastly different to that suggested by the original EPC; therefore it has also been calculated in RdSAP 2005 as well. The annual 2005 methodology calculates a SAP value of 26, which is much closer to the accredited assessed value of 19. According to Figure 5.8 the 2009 value for CS5 should be nearer 25, and unlike for CS1, the result suggests that the input has led to a different rating between the 2005 and 2009 methodologies, rather than just the calculation itself.

In summary, the importance of the *assessor* has been highlighted but also the effects of the differences in *calculation* between methodologies. Analysing the ability of the methodologies to capture and represent energy usage of the dwelling is now returned to.

## 5.4 Steady State assessment of Thermal Mass Parameter

In Chapter 4 the findings of CS3 and 4 suggested that while thermal mass is utilised within the calculation using a Thermal Mass Parameter (TMP), and can impact on the estimated internal temperatures, it was found that there was no clear correlation using just two dwellings. Here, calculations have been carried out across all 5 case studies to ascertain if any consistent feature can be down to TMP alone. Table 5.2 shows the TMP used in each steady state calculation for each case study, with the SAP-defined banding of thermal mass levels shown in Table 5.3.

**Table 5.2 Thermal Mass Parameter summary**

| TMP ($kJ/m^2K$) | CS1 | CS2 | CS3 | CS4 | CS5 |
|---|---|---|---|---|---|
| **RdSAP 2009 default** | 250 | 250 | 250 | 250 | 250 |
| **RdSAP 2009 if assessed** | 180 | 85 | 192 | 267 | 204 |
| **SAP 2009** | 181 | 85 | 197 | 332 | 210 |

**Table 5.3 Indicative values of TMP, taken from Table 1f (BRE, 2010)**

| Thermal Mass | TMP ($kJ/m^2K$) |
|---|---|
| Low | 100 |
| Medium | 250 |
| High | 450 |

Using these indicative values, it can be said that while RdSAP assumes a medium level of thermal mass in all five dwellings, the detailed calculation in SAP calculates a TMP that correlates with medium-mass for CS1, CS3, CS4 and CS5, and low- mass for CS2. While at first glance this seems to suggest that the assumption of medium mass is a valid assumption, the difference between the medium mass TMP of 181 kJ/m$^2$K in CS1 and the medium mass TMP of 332 kJ/m$^2$K is large and may have repercussions on the calculation outputs.

To investigate this further, the SAP calculations for each case study have been forced to assume three levels of TMP and the internal temperatures have been compared with that given by the RdSAP 2009 calculation. The consistent finding from the results in Figure 5.9 is that the higher the TMP in SAP, the higher the internal temperatures. Likewise, the lower TMP gives the lowest internal temperatures. However, that is the only consistent finding. There is considerable variation across the case studies with respect to where the RdSAP assessment is in relation to the SAP assessments. For example in CS3 and CS5 the RdSAP assessment predicts higher temperatures than in any of the SAP assessments, despite using the medium TMP. This suggests that differences exist between the SAP and RdSAP methodologies in addition to the assumption of thermal mass, that are responsible for internal temperature (and beyond that, space heating demand).

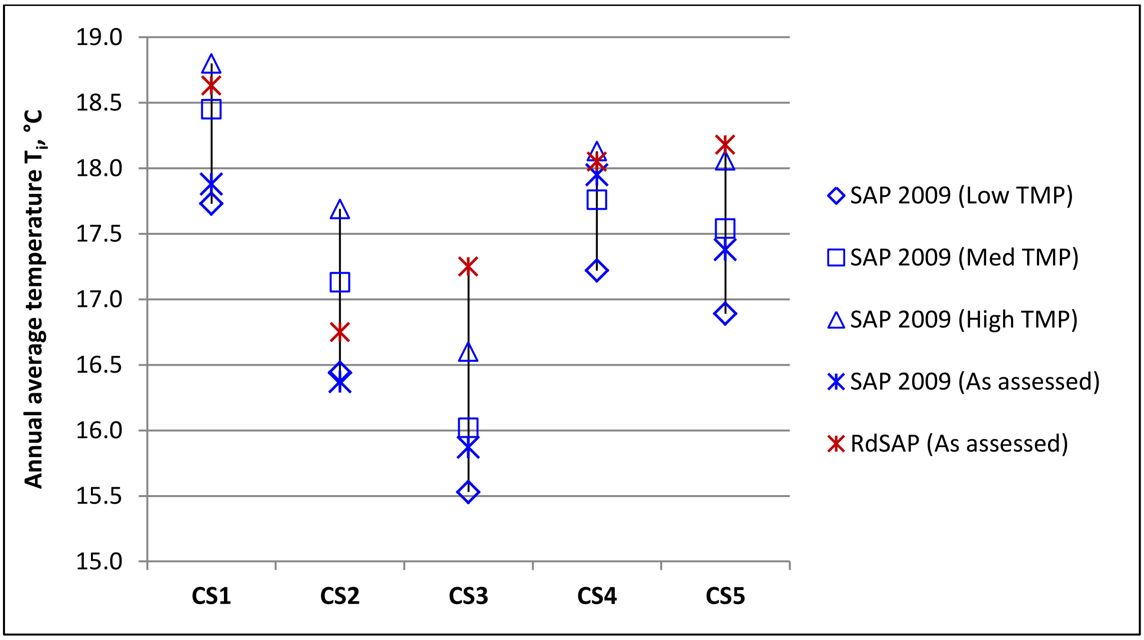


**Figure 5.9 Annual average internal temperature with varying TMP**

Additionally, there is a difference in the range of temperatures seen depending on dwelling type. For example the predicted temperatures for CS3 are from 15.53°C up to 17.25°C, a 1.72°C range, whilst in CS4 the range is 17.22°C to 18.13°C, a range of 0.91°C.

These differences can be significant when calculating the space heating requirement within an assessment. With CS4, the average temperature used by RdSAP 2009 is just 0.05°C higher than that to which the space is heated in the calculation, with SAP 2009 calculating the average internal temperature at 0.05°C lower than the 18°C specification. In CS3 however, the RdSAP 2009 internal temperature is 0.75°C lower than the specification, and the SAP 2009 internal temperature 2.03°C below the specification temperature. These results appear to match the findings in Aste (2009) that the higher the thermal inertia the lower the heating demand (seen here as higher internal temperatures).

Already discussed is the impact that the improved fabric heat loss has on CS4 over CS3, but looking at the remaining case studies alongside these two results the initial findings are strengthened: further investigation is needed into the inclusion of thermal mass within the steady state calculation methodology; into the default thermal mass used within RdSAP; or into collecting data on the thermal mass of traditional wall constructions to better inform the calculations.

Comparison can be made between the RdSAP 2009 assessment and the SAP 2009 assessment using the medium level of TMP. These two calculations are using identical TMPs, so the difference in internal temperature identified in Figure 5.9 is unrelated to TMP and alternative reasons need to be sought.

## 5.5 Internal Gains

The calculations for internal temperature depend on TMP, heat loss, the external temperature, the heat emitters (radiators), the hours the heating system is on, and the internal gains. In all methodologies and case studies the emitters, heating hours, external temperature (and in the case of RdSAP the TMP) are all identical, therefore cannot be responsible for differences in internal temperature. The level of internal gains will however differ between case studies and across methodologies. The monthly internal gains from each methodology are shown in Figure 5.10 to Figure 5.12, with the hourly results from IES shown as a monthly weighted average.

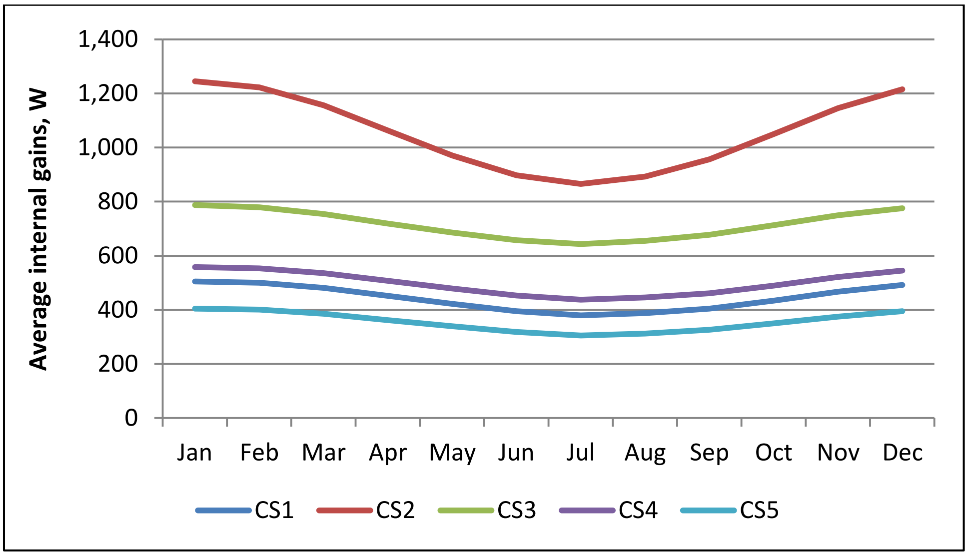


**Figure 5.10 Internal gains each month from SAP 2009**

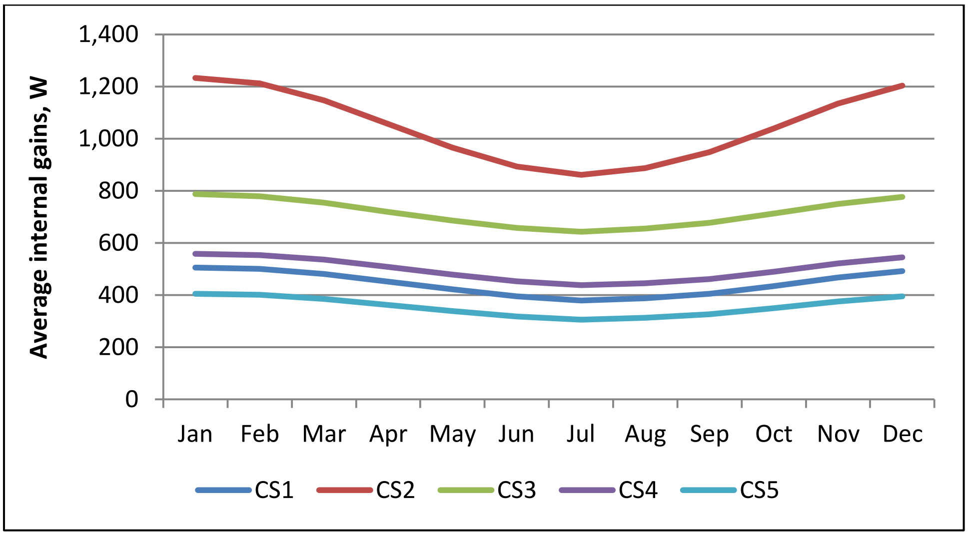


**Figure 5.11 Internal gains each month from RdSAP 2009**

The SAP 2009 and RdSAP 2009 results are identical, as the calculations identified in section 3.5.12 are based on floor area and occupancy, which are identical in both methodologies. There is an obvious difference between case studies; however this has been analysed with respect to the differences between CS3 and CS4 in section 4.3.3.

This section will therefore discuss the internal gains estimated by IES (Figure 5.12).

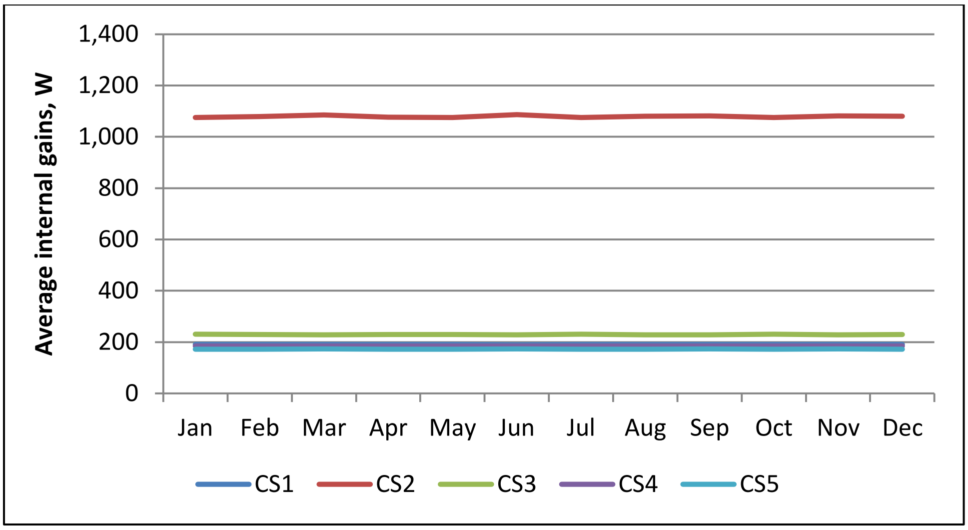


**Figure 5.12 Internal gains each month from IES**

The first item of note is that the gains appear flat throughout the year: this is because the figure shows monthly internal gains, rather than the half hourly gains calculated with IES. The dynamic calculation allows a single 24hr period to be examined, although this will not be done here. The second item of note is the similarity of all the case studies, except CS2 – the much larger house. When the gains are broken down into metabolic, lighting and solar gain, the reasons for this become clearer (Figure 5.13 to Figure 5.15).

Both the metabolic and lighting gains in IES are related to the number of days in the month as they are reliant on the occupancy profiles entered into the software. There are both weekday and weekend occupancy profiles, leading to a relatively flat profile across the year depending on the number of weekdays and weekends in the calendar month in IES.

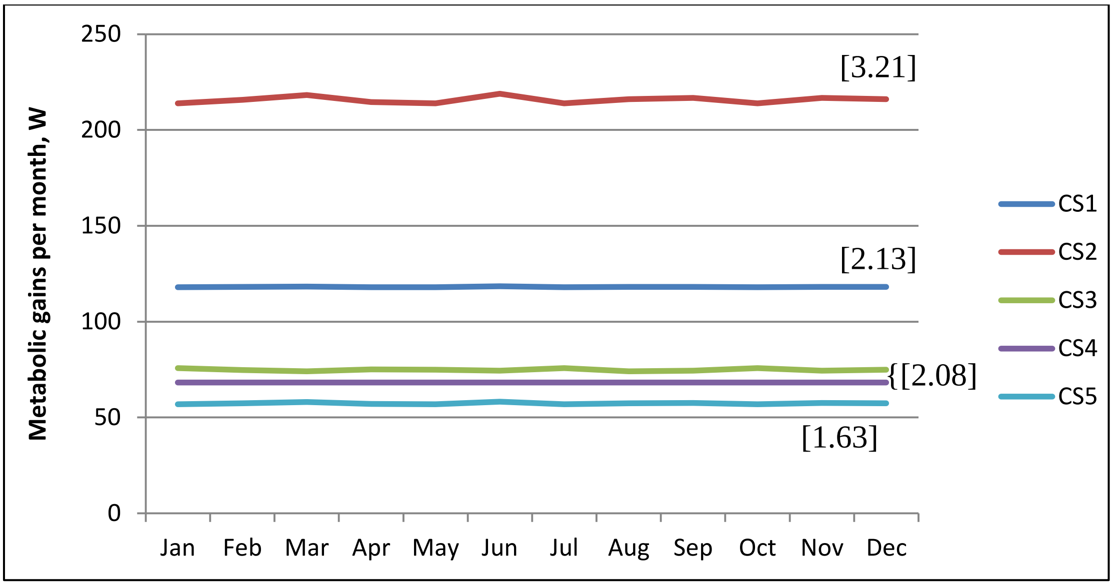


**Figure 5.13 Metabolic gains throughout a year as calculated by IES. Numbers in square brackets represent number of occupants input to IES.**

It is clear from Figure 5.13 that the number of occupants entered into the dynamic simulation are important, more so than the activity profile of those occupants, i.e. when they are in the dwelling and in which rooms. Interestingly CS2, which has double the number of occupants to CS5, has far more than double the metabolic gains. It may be of benefit in further research to utilise a case study such as CS2 which has such large variation in occupancy profile potential (see Section 4.2.4), by forcing different numbers of occupants into the dynamic calculation to ascertain the relationship between number of occupants and metabolic gain, to better inform the steady state model's calculation of the same.

Figure 5.14 again shows the difference between CS2 and the other case studies. In IES, the lighting usage is related to the precise type of lighting used in each room, and the hours of use. The almost flat plots on this chart once again reflect the nature of averaging a monthly value based on number of weekdays and weekends.

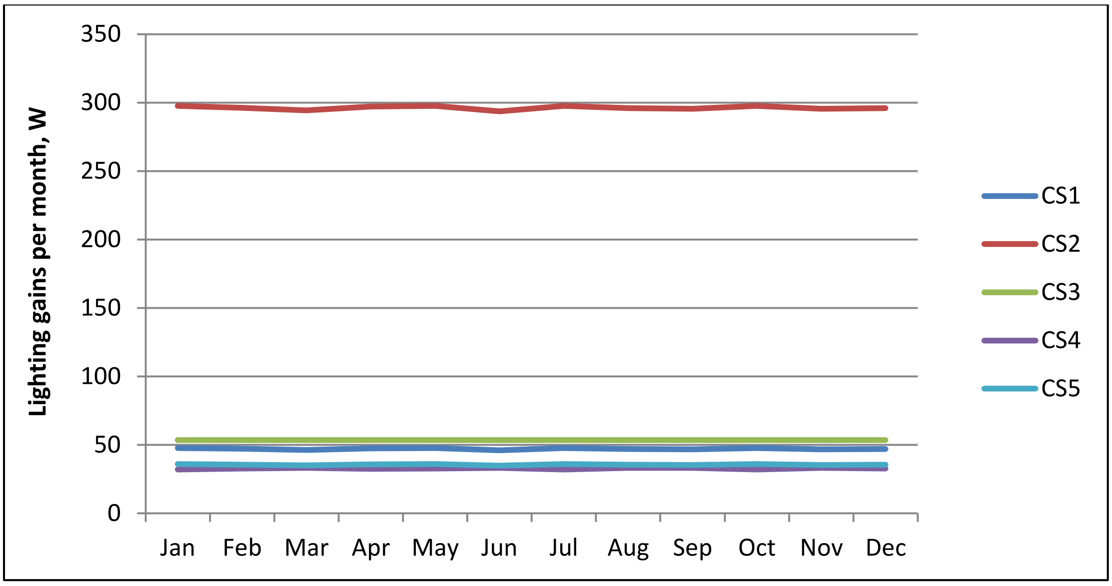


**Figure 5.14 Gains from lighting as calculated by IES**

The solar gains (Figure 5.15) vary according to the seasonal variation in solar radiation, the area of glazing facing each orientation, and the type of glazing. The difference between types of glazing can be seen in the difference between the single glazed CS3 and double glazed CS4. Interestingly, while CS5 has reduced gains through south facing windows (double glazed), CS1 which only has east/west facing windows has higher gains through single glazed windows. This result suggests that the orientation is less important than the type of glazing, which could in turn suggest that the assumption in RdSAP that windows are all east/west facing is in fact not as erroneous as it was initially considered.

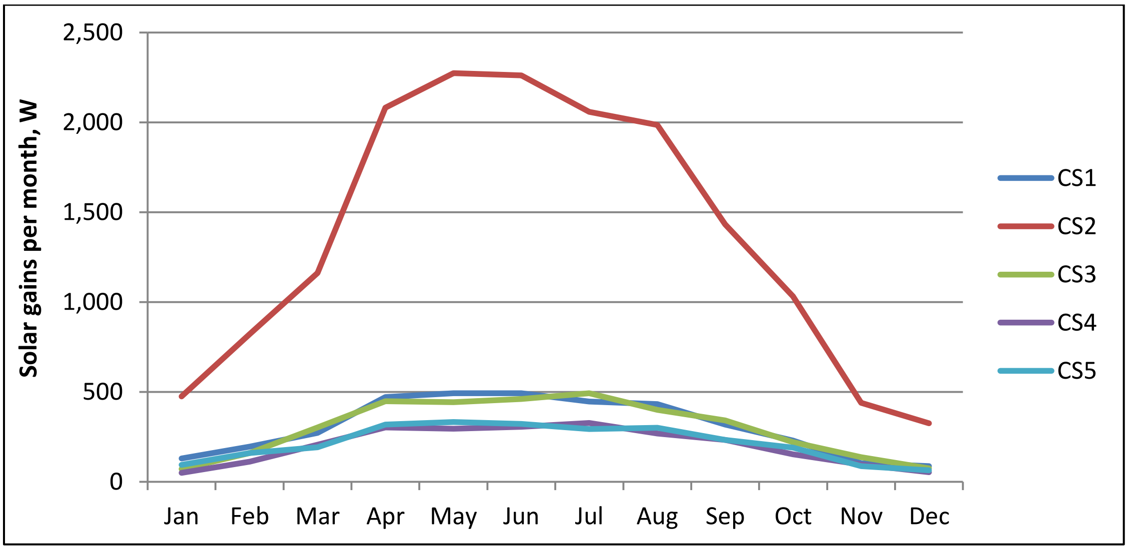


**Figure 5.15 Solar gains across the seasons, as calculated in IES**

## 5.6 Dwelling type

It has been found in previous sections that there are variations in most parameters across the dwellings, which causes difficulty in drawing conclusions. As previously suggested when looking at heat loss in Chapter 4, this may be due to the dwelling type. Here it is questioned whether the type of dwelling can be influential in determining the level of heat loss from a dwelling. However, to understand what effect this can have on the energy demand both the heat loss area and dwelling size must be considered. Table 5.4 shows the difference in impact of heat loss area on space heating demand, as calculated by RdSAP 2009.

**Table 5.4 Effect of dwelling type on space heating requirement in RdSAP 2009**

| | CS1 | CS2 | CS3 | CS4 | CS5 |
|---|---|---|---|---|---|
| Total heat loss area ($m^2$) | 52.63 | 596.14 | 192.08 | 192.08 | 160.38 |
| Total floor area ($m^2$) | 65.44 | 361.42 | 63.54 | 63.54 | 47.97 |
| Space heating demand (kWh/year) | 6,244.4 | 72,541.0 | 18,391.2 | 9,673.1 | 7,301.0 |
| Space heating demand per $m^2$ floor area (kWh/$m^2$/year) | **95.4** | **200.7** | **289.4** | **152.2** | **152.2** |

The above table highlights the significance of dwelling type and therefore heat loss area on the overall space heating demand. For example, CS5 is the smallest property but does not have the smallest space heating demand. Common sense suggests this is because CS5 is a bungalow with greater heat loss area, rather than a mid-floor flat, considering they have the same construction type – and therefore identical U-values within the calculation methodologies. To determine if this the case, the level of space heating demand per square meter of total floor area is used, removing the size of the dwelling as a factor, leaving only the heat loss area and magnitude. (By comparing heating demand rather than heating requirement, the values analysed are indicative of the heat loss of the dwelling, rather than the efficiency of the heating system.) The values in Table 5.4 are also displayed in Figure 5.16 to analyse any correlation from these five case studies. The linear trend line fitted on Figure 5.16 has an $R^2$ valued of 0.95, indicating a high correlation. However, the value for CS2 clearly has an effect, and without it the four remaining data points provide little correlation confidence.

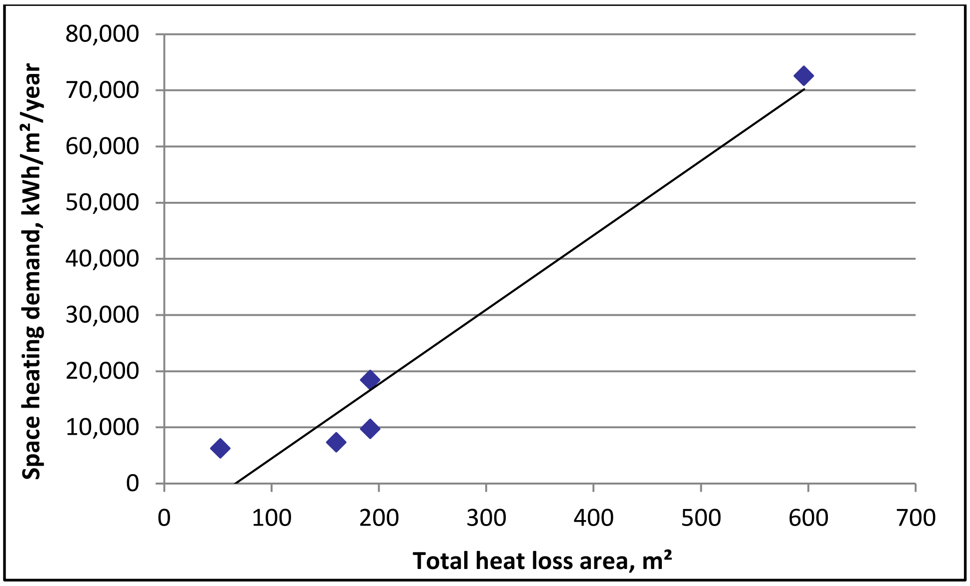


**Figure 5.16 Relationship between total heat loss area and space heating demand, as calculated in RdSAP 2009**

An additional method of analysing the effect of heat loss areas on space heating demand is to look at a new parameter: the ratio of heat loss area to floor area denoted here using $R_A$. This is simply calculated by dividing the total heat loss area by the total floor area, and can be used to compare similar sized properties, such as CS1, CS3 and CS4.

**Table 5.5 Heat loss to floor area ratio, $R_A$**

| | CS1 | CS2 | CS3 | CS4 | CS5 |
|---|---|---|---|---|---|
| Total heat loss area ($m^2$) | 52.63 | 596.14 | 192.08 | 192.08 | 160.38 |
| Total floor area ($m^2$) | 65.44 | 361.42 | 63.54 | 63.54 | 47.97 |
| **Heat loss to floor area ratio, $R_A$** | **0.80** | **1.65** | **3.02** | **3.02** | **3.34** |

This table confirms that the bungalow (CS5) is the ‘worst’ dwelling type for level of heat loss, and that despite being the largest case study, CS2 has half the heat loss area per square meter of floor area than CS5, the smallest. The difference in dwelling type is now obvious, with the small detached dwelling (CS3 and CS4) having a ratio, $R_A$, of three times that of the mid-floor, mid-terrace flat (CS1), despite their similar floor area.

Furthermore, combining the results of Table 5.4 and Table 5.5, it is shown that CS1 has both a low $R_A$, and a low space heating demand, leading to 95.4kWh/$m^2$/year space heating demand. In comparison, CS5 has a similar low space heating demand but high $R_A$, estimating a space heating demand of 155.7kWh/$m^2$/year. CS3 and CS4 are the same size and have the same $R_A$, but have very different heating demand, which is down to the level of heat loss through the improved walls in CS4. Accordingly, CS4 has a lower space heating demand per square meter.

By comparing the space heating demand per floor area with the heat loss area ratio in graphical format (Figure 5.17) it is clearer to note the improvement in heat loss magnitude from CS3 to CS4. However, the $R^2$ correlation value is just 0.21, suggesting that the correlation is not significant unlike that between space heating demand and heat loss area.

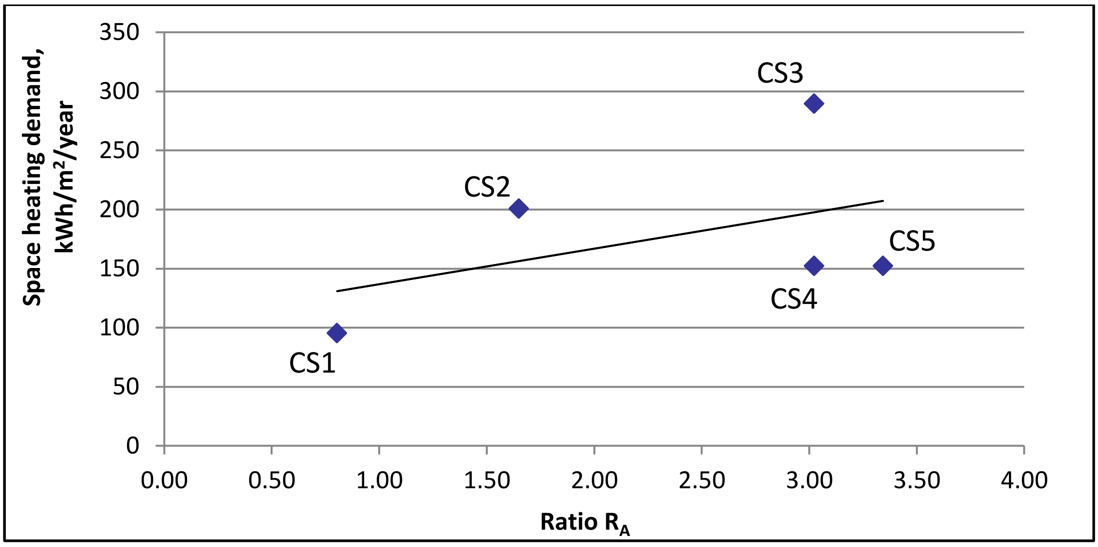


**Figure 5.17 Relationship between space heating demand and heat loss ratio**

These findings are interesting to note, and these results can be applied to all UK dwellings using the RdSAP methodology, not just Scotland. If data were available, it would be worth comparing dwellings with the traditional construction techniques used in these five case studies, against results from a much wider study incorporating alternative construction techniques.

## 5.7 Location

The type of dwelling has been shown to be important when calculating the energy demand of a property, but as discussed earlier, the internal and external temperature are of importance when assessing space heating demand.

As seen with CS1, the location variables used within SAP, RdSAP and IES all differ. However, improvements within SAP and RdSAP have been made, with regional climate data now used in RdSAP for calculations towards energy savings. For compliance with Building Standards and the EPC, the UK average data is still used, but as it is used for a comparison of typical dwellings across the UK this method of calculation is still relevant. It is suggested here that the average running costs on the EPC are displayed in such a way that makes it clear to the householder the difference they can expect with their dwelling in its actual location. Because the improvements in the climate data used in versions of SAP and RdSAP are beyond the scope of this project, no further analysis has been carried out with respect to location of dwelling.

## 5.8 Lighting

Whilst the energy saving benefits of new compact fluorescent lighting has long been established (as discussed in Section 2.5.2), the interactions that lighting has within the energy models can still be discussed further here. The significance of the lighting choice can most clearly be seen across CS3 and CS4. Traditional tungsten lighting was used in CS3, while in CS4 with all the refurbishment work, the lighting was changed to CFLs. This dramatically reduced the energy for lighting, from 572 kWh/year to 286kWh/year, according to RdSAP 2009. However, the space heating requirement could be expected to go up as CFLs are more efficient and release less heat to a space. The internal gains calculated within SAP and RdSAP include a parameter for gains from lighting. Table 5.6 and Table 5.7 show the comparable levels of gains from the two different types of lighting across the year, using RdSAP 2009, SAP 2009, and IES<VE>.

**Table 5.6 Internal gains due to traditional incandescent lighting for CS3, all figures kWh/month**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAP 2009** | 81.4 | 72.3 | 58.8 | 44.5 | 33.2 | 28.1 | 30.3 | 39.4 | 52.9 | 67.2 | 78.5 | 83.6 |
| **RdSAP 2009** | 81.0 | 71.9 | 58.5 | 44.3 | 33.1 | 27.9 | 30.2 | 39.2 | 52.7 | 66.9 | 78.1 | 83.2 |
| **IES<VE>** | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 |

**Table 5.7 Internal gains due to retrofitted low energy lighting for CS4, all figures kWh/month**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAP 2009** | 40.7 | 36.1 | 29.4 | 22.2 | 16.6 | 14.0 | 15.1 | 19.7 | 26.4 | 33.6 | 39.2 | 41.8 |
| **RdSAP 2009** | 40.5 | 35.9 | 29.2 | 22.1 | 16.5 | 13.9 | 15.1 | 19.6 | 26.3 | 33.4 | 39.0 | 41.6 |
| **IES<VE>** | 31.0 | 31.6 | 32.1 | 31.3 | 31.5 | 31.9 | 31.0 | 32.1 | 31.9 | 31.0 | 31.9 | 31.5 |

The internal gains with low energy lighting are exactly half the gains due to tungsten lighting in both SAP 2009 and RdSAP 2009. This is due to the correction factor, $C_1$, used by the steady state methodologies to determine lighting gains and electrical requirement, as seen in Section 3.5.10. It is the ratio in Equation 3.14 that leads to the halving on energy requirement when replacing all traditional lighting outlets with low-energy outlets. The small variations in monthly energy requirement for lighting calculated in IES are due to the same reasons as outlined in Section 5.5.

## 5.9 Summary

This chapter has combined the results of the individual case studies to ascertain if any trends exist with respect to whether a single methodology behaves the same towards all five case studies. It has been seen that this is not the case. The following chapter will discuss these findings in the context of the overall objectives of the research project and the applicability of the findings to both the heritage and built environment sectors.

# CHAPTER 6 - DISCUSSION

This penultimate chapter discusses the methods used in this research, as well as the findings suggested by the data. A more generic review of the findings will follow in Chapter 7.

## 6.1 Methods of Analysis

### *6.1.1 The energy assessment methodologies*

Three energy assessment methodologies were used in this research: SAP 2009 (v9.81), RdSAP 2009 (v9.90) and the IES Virtual Environment (v6.4). Investigations undertaken in the early stages of the project also used RdSAP 2005 (v9.80), while investigations undertaken for additional research projects have used RdSAP 2009 (v9.91). The RdSAP 2005 methodology was excluded from the results analysis after it was superseded in 2010, after which assessments were required to use v9.90.

Across Chapter 4 and Chapter 5, particular methodologies were highlighted in some cases, and excluded in others. For example, in all analysis, RdSAP 2009 is used, as the Government accredited tool for assessing energy use in existing dwellings in the UK. When studying internal temperature for CS3 and CS4, IES has been analysed, as it provides far greater depth of results, and allows a comparison of individual rooms on an hourly basis, while the steady state methodologies do not allow this. This provided an understanding of how individual rooms react with respect to internal and external variables such as temperature. Additionally, the results for internal gains are analysed from IES only, as the results between the two steady state models are identical.

The balance of benefits and drawbacks of the methodologies were suggested in Section 2.7.3. Here, these are expanded on by including the results of the research carried out and experiences gained during the course of the research. Note that the entries in this table are for calculations towards Energy Performance Certificates, and do not include the expected upgrades to RdSAP in 2013.

**Table 6.1 Benefits and drawbacks of the methodology types used in this research project**

| | SAP | RdSAP | Dynamic |
|---|---|---|---|
| Construction details | Exact, from plans | Database unless known | Database unless known |
| Window orientation | ✓ | ✗ | ✓ |
| Room-by-room | ✗ | ✗ | ✓ |
| Thermal Mass | ✓ | ✗ | ✓ |
| Include heat gains | ✓ | ✓ | ✓ |
| Overheating risk | ✓ | ✓ | ✓ |
| Climate resolution | Monthly | Monthly | Hourly |
| Climate location | UK | UK | Regional |
| Time to assess | 1hr | 1-2hrs + site visit | 2-3 days + site visit[a] |
| Cost to assess | Low | Med | High |
| Gives energy costs | ✓ | ✓ | ✓ |
| Gives emissions | ✓ | ✓ | ✓ |

**Notes:**

[a] Dependent on complexity of dwelling. CS2 took a few weeks to input due to complicated geometry whereas CS3 was done in a day.

In addition to the above table, it should be noted that the complex input required by IES at times showed the software to be not suitable for dwellings of this nature. This was experienced mostly in CS2 and CS5, which had multiple roofs. The rooms in the roof in CS2 also created difficulty with the software's sensitivity unable at times to recognise where wall met roof, and dormer windows were therefore a far more time consuming aspect of the assessment than in a steady state model which does not require the dwelling to be drawn 3D into software. The sensitivity comes from the detail within IES, which will calculate coordinates to 30 decimal places, and it was common to be given a coordinate of -0.000000, leaving the user unable to correct the issue without re-drawing the space. The issue of the software unable to recognise geometry was also experienced in CS2 with the windows in the tower rooms. IES cannot draw a circular space; instead it creates an 8- or 16-sided shape. When wishing to apply a window, the software therefore cannot put a window wider than any one of these wall sections. Rather than entering a window dimension, the assessor can select to apply the window to 100% of the width, which was utilised, but again the sensitivity of the software was unable to repeat this for all tower windows. It is these additional issues that come from drawing the dwelling in 3D, that make dynamic simulation a less attractive option, despite any perceived accuracy benefits.

### *6.1.2 Measured data*

Model accuracy is important, but how accurate a model needs to be and it's perceived success can differ depending on the user and use. If the methodologies here follow the *profile* of measured data, but don't predict the *magnitude* correctly, can that be considered accurate? In Section 4.1.3, comparison was made between the calculated values from the methodologies, and the measured data from the occupant: this option was only available for CS1. Data was unavailable for CS2 as it is used as government offices and the difference in energy use between a dwelling and an office environment is too great. Data was unavailable for CS3 as it was unoccupied and had been for some time. Similarly, CS4 was also unoccupied at the time of writing; at the time of the site visit the retrofit measures were still on-going. CS5 used a pre-pay meter for electricity, and while anecdotal evidence as to bills was available, it was not sufficient to allow robust comparison. The payment from the occupant to the landlord was made monthly for the LPG, while the landlord only received statements when the tank was filled, followed by a credit or debit note the following year.

Therefore except CS1 it has been impossible to compare the methodologies with measurements for these case studies. It can be argued however, that this research has focussed on a comparison of the methodologies themselves, understanding them in great depth, rather than comparing them with a true situation. At the start of the research, it was thought that as the steady state methodologies were used as compliance tools only, 'representativeness' was not the most important factor. However at the end of the research this view has developed as the methodologies are increasingly being used for energy advice. In 2018, when it is envisaged that all dwellings must be at least an E-rating before they can be sold or let, there must be confidence that the methodology is not only accurate but also representative of the dwelling in question.

## 6.2 Monthly Calculation impact

It is this quest for accuracy and precision that led to the BRE updating the SAP methodology in 2010 from an annual calculation to a monthly calculation. As stated in the previous section, calculation had initially been carried out using the previous, annual, methodology. A comparison between the annual and monthly calculations is shown in Figure 6.1 by comparing annual space heating demand. Whilst Figure 6.1 suggests that no single methodology consistently predicts highest or lowest space heating demand, it is seen in all five case studies that the space heating demand is larger in the annual RdSAP 2005 than in the monthly RdSAP 2009.

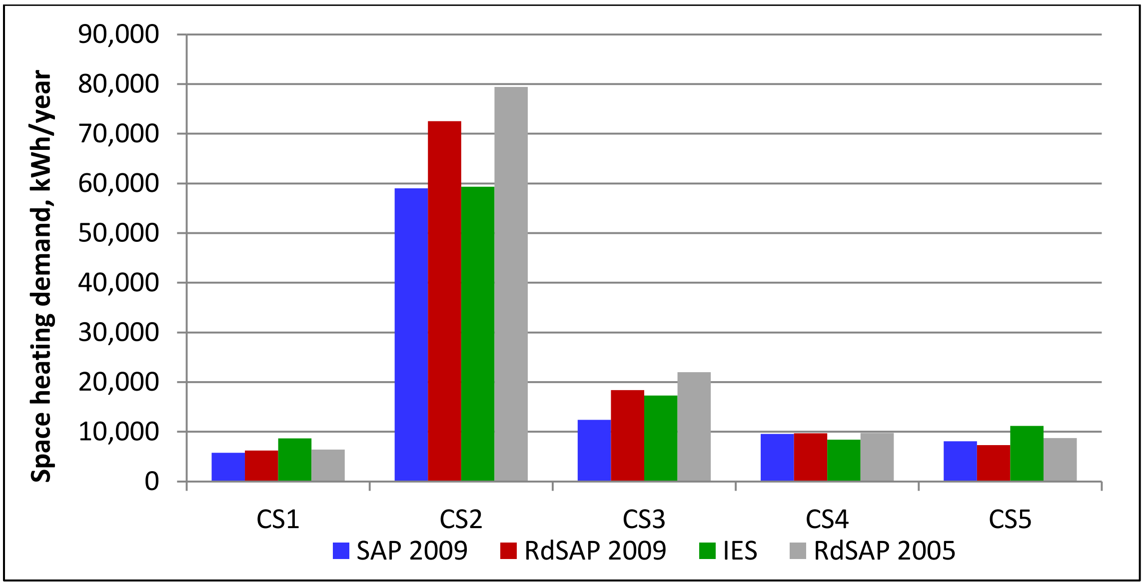


**Figure 6.1 Annual space heating demand including the superseded RdSAP 2005 methodology**

An alternative method of seeing the difference that a monthly calculation has is to look at month by month results (Figure 6.2). It is immediately obvious from Figure 6.2 that for these two case studies, the annual internal gains are higher than those calculated by the monthly calculation. While this would suggest a lower space heating demand, the RdSAP 2005 calculation also used slightly worse (higher) U-values, which are responsible for the higher space heating demand seen in Figure 6.1.

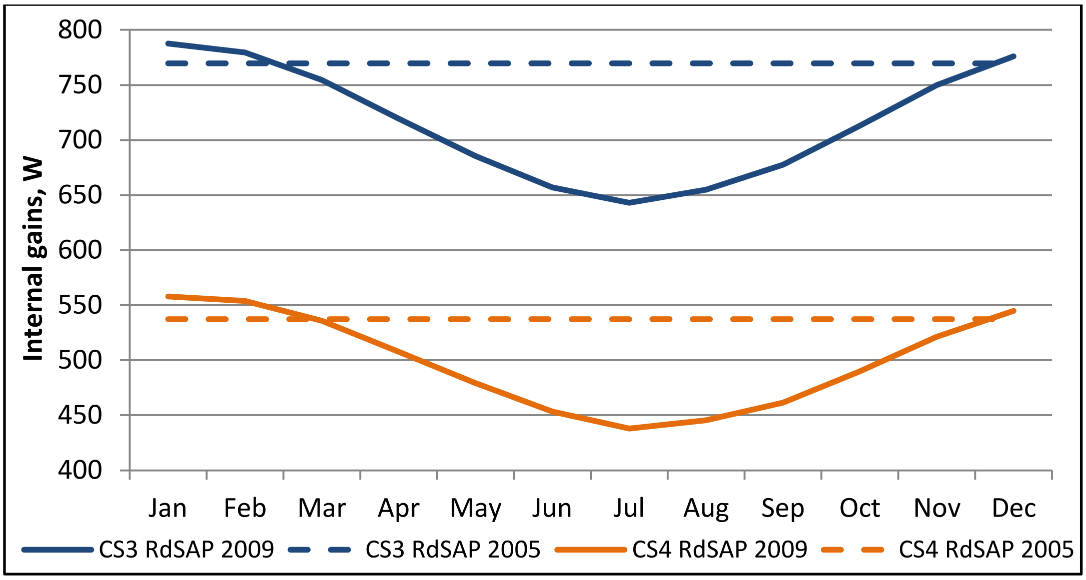


**Figure 6.2 The difference between annual and monthly calculated internal gains for CS3 and CS4**

Whilst it is useful to analyse CS3 and CS4, the remaining case studies must also be included to check if the difference between RdSAP 2005 and 2009 holds for other dwelling types.

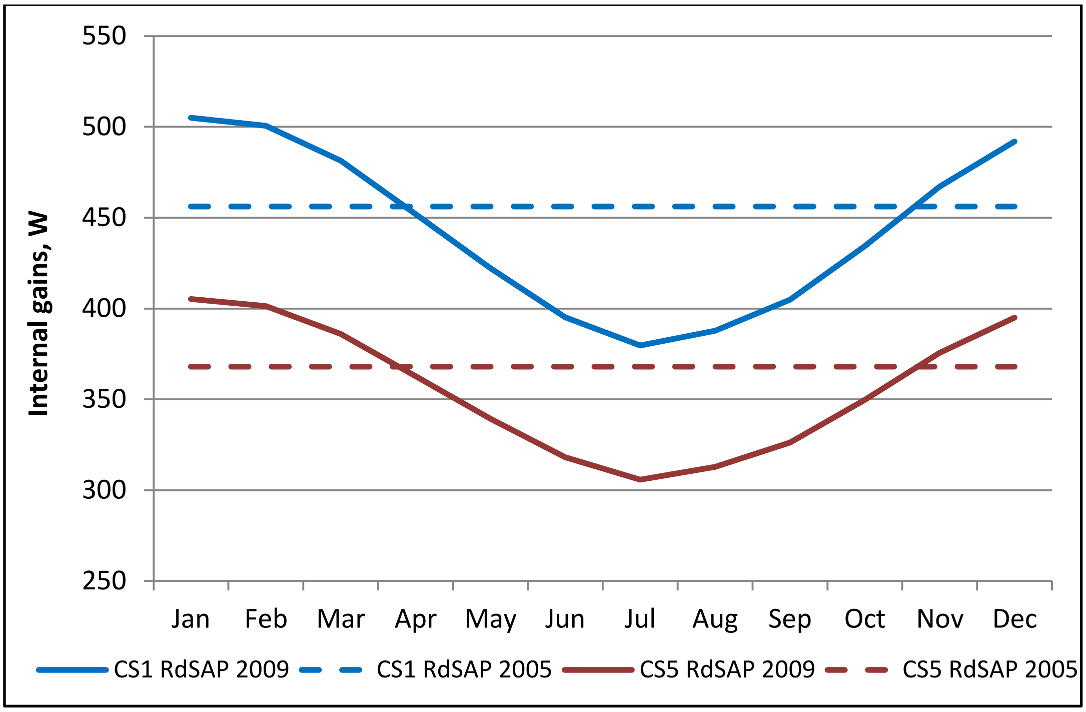


**Figure 6.3 The difference between annual and monthly calculated internal gains for CS1 and CS5**

Figure 6.3 once again shows the difference between the monthly and annual calculation methodology this time for CS1 and CS5. In these dwellings, the annual gains appear much closer to the average of the monthly calculated values of internal gains.

Finally, the internal gains in CS2 are reviewed across the methodology types. This dwelling is shown separately due to the larger gains involved:

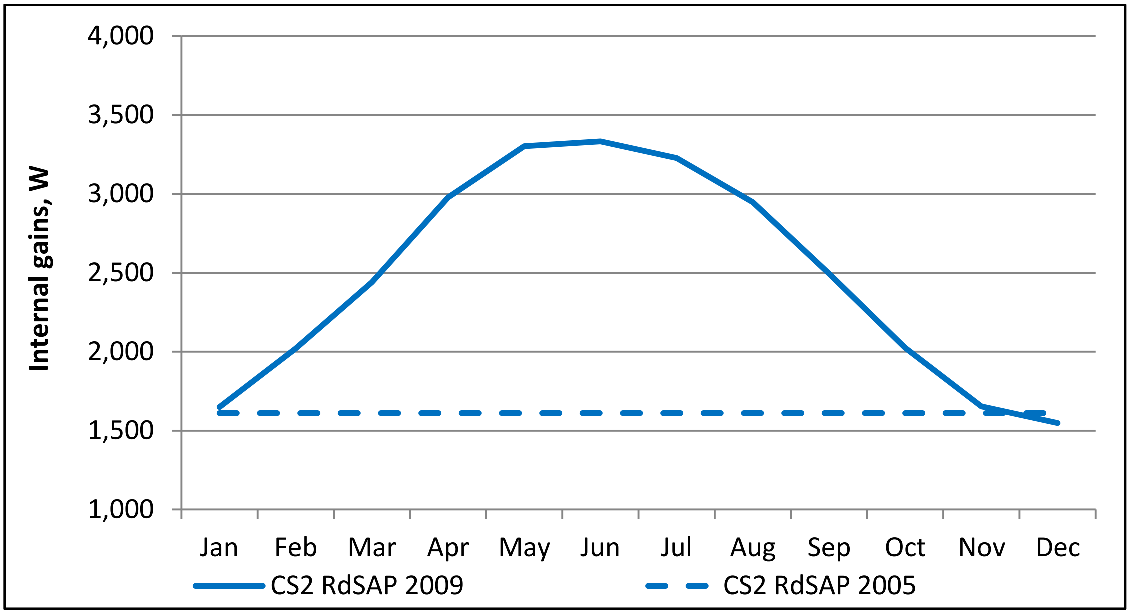


**Figure 6.4 The difference between annual and monthly calculated internal gains for CS2**

Once again showing a difference between the monthly and annual calculation methodologies, the internal gains associated with CS2 are lower in the annual calculation than they are in the monthly calculation (Figure 6.4). This is a converse result to that seen in CS3 and CS4, and is most likely due to the calculation of gains in RdSAP 2005. In RdSAP 2009 the internal gains are calculated individually as those from lighting, metabolic, appliances and cooking. In RdSAP 2005, these are calculated as one figure, dependent on total floor area: the point at which the calculation changes is a TFA of 282m$^2$, therefore the internal gains in CS2 are calculated using a different equation than for the remaining cases studies as it is the only case study with a TFA larger than 282m$^2$. In RdSAP 2009, no such distinction between dwelling size exists for internal gains.

It can be said that the move to a monthly calculation has improved the precision of the calculation, and this may help with improving the perception of energy assessment, as well as providing additional confidence in results of the assessment.

## 6.3 Reduced data or SAP?

While the precision of a monthly assessment appears to improve results, there is also debate as to the level of assumptions made in RdSAP when compared to SAP. This has been reviewed throughout Chapter 4 and Chapter 5, and will be summarised here.

The key assumptions made in RdSAP are that of the window orientation and area, floor insulation, roof U-value and wall thickness therefore wall U-value. As the findings drawn throughout these chapters have not found variables to be calculated consistently across methodologies, it cannot be said that there are benefits of using one methodology over another. However, using input data that is exact to the dwelling in question will create a more accurate assessment even if the assessment still cannot *recreate* the energy usage in the dwelling through the calculation. For the purposes of EPCs for home reports, standardisation is the aim; therefore 100% accurate recreation of true energy use is not required. Caution should be given to using EPCs therefore for alternative uses, such as setting minimum ratings.

Many of the assumptions within RdSAP are those that can be amended by the assessor if the information is available. If the assessor has access to the roof and can measure loft insulation, the exact depth of insulation should be entered into the calculation. It is possible to do a simple assessment using just defaulted assumptions, to speed up the assessment process, thereby increasing profit from each assessment. This is a process which needs additional focus from accreditation bodies, training centres and the government, to ensure those commissioning assessments are given fair treatment. The improvements made to RdSAP in 2012 are bringing the SAP and RdSAP methodologies closer together in terms of input, but only when the use of 'default' information is minimised.

## 6.4 Steady State or Dynamic Simulation?

This research has highlighted some of the shortcomings of the steady state method and explored the benefits and drawbacks of these as well as alternative methods. By comparing the steady state methodology with one such alternative (IES) a number of discussion points arise. Had the research utilised alternative dynamic simulation tools or tools from other countries, these points may have been different.

### *6.4.1 The assessor*

The ability of an assessor is continually evaluated to ensure fair and quality examination of a dwelling's energy and carbon performance. The training given to assessors typically involves reading around the subject, some home study, and a week-long intensive course that includes a site visit, followed up by examinations. Assessors involved in new-build EPCs have similar training but with a focus more on site plans and no site visit (personal experience of the author). There is a danger that assessors can complete assessments as a numbers exercise, without fully understanding the building physics and what is affecting the calculation. This issue would only be exacerbated if dynamic simulation were used, due to its additional complexity and requirements on the assessor.

For example, as an RdSAP assessor, no understanding of thermal mass is needed, as the value is assumed. As a SAP assessor, tables are used to assume values for individual elements which are then collated to calculate a dwelling thermal mass parameter based on the materials in the construction. For an assessor using dynamic software, additional knowledge and understanding is required as the material depth, density, thermal conductivity and thermal resistance must all be entered. The default settings in the software may not always be accurate and checks must be made. As the dynamic software is currently used primarily for non-domestic properties, a domestic assessor would be required (as was for this research project) to add constructions to the software.

### *6.4.2 Location*

Section 4.1.2 explored the difference that local climate data could make to a calculation; therefore no additional assessment is carried out here. However it is noted that updates to the steady state methodology in 2013 include the ability to enter local climate data, therefore there is no longer any advantage with respect to local climate of using dynamic simulation.

### *6.4.3 Heating zones*

Both CS2 and CS5 referred to the use of zones or identifying particular rooms in a dwelling, to shape the space heating demand. As Section 4.4.2 found, the ability of the methodology to recognise a draught lobby made an improvement to the calculation. In dynamic simulation, individual rooms are not only given an ‘activity’, heating profile and hours of use, but it is also identified whether they have external walls and openings. For this research, the air infiltration rate was set to be identical in every room, but this could be altered by an assessor if there was enough evidence to suggest such a route should be taken. If the additional module “MacroFlo” was used in the IES VE software, this would have also added to the ability of the simulation to account for air flow through each room, moving warmth or cool from one room to another.

## 6.5 What the results mean

The ability of a model to represent energy use within a dwelling has consequences for multiple stakeholders and industry professionals. In alignment with the reviewed literature in Chapter 2, the following paragraphs discuss the implications of the results of this research project on the conservation and heritage sector; policy; domestic energy use; the occupants; and on the use of models for continued energy-related decision making.

### *6.5.1 For the heritage sector*

The results from these five case studies have shown that it is possible for traditionally constructed Scottish dwellings to gain higher Energy Performance Certificate (EPC) ratings than public perception, as in the case of CS1. However, these ratings are highly dependent on the dwelling type, and for larger or more exposed properties such as CS2 and CS3 the perception holds, that stone-built dwellings are inefficient with respect to energy: four of the five case studies were given lower than an E rating.

In Section 5.1 it was seen that across all five case studies, the lowest space heating and DHW proportion is at CS1, at just under 96%; the highest is CS3 at just under 99%.

This suggests that buildings of this construction type are much worse than the UK average, which may damage the ‘do it up’ side of the ‘knock it down or do it up’ debate in the heritage sector.

It has typically been the case that buildings in conservation areas or those listed have either been exempt from energy aspects of the Building Standards or are treated on a case-by case basis (Scottish Building Standards Agency, 2007; DCLG, 2010), in an effort to conserve the building. In more recent guidance – such as the most recent Building Standards (Scottish Building Standards Agency, 2013) and the European Energy Efficiency Directive (EED) (European Parliament, 2012) there has been a shift: indicating the necessity of all dwellings to reach certain energy standards in order to reach national and European carbon and renewable energy targets. New standards and guidance typically expect existing dwellings to improve energy efficiency by including phrasing such as ‘where reasonably practicable to do so’, ‘flexible approach’ and ‘compatible’. However, the EED enables Member States to decide individually whether to force energy efficiency improvements on historical buildings in cases where:

> “…compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance.”
>
> (European Parliament, 2012, p16)

These caveats imply that improving energy efficiency should be attempted. Reasons for not carrying out a retrofit measure may be financial (e.g. the payback is too long or capital cost is prohibitive), or that it would be to the detriment of the characteristics of the property (e.g. external wall insulation applied to a mid-terrace town house in Edinburgh’s New Town, part of the World Heritage Site, an extreme example). A number of organisations are researching the ability to combine energy efficiency and low carbon energy sources into culturally sensitive buildings, e.g. the retrofit work carried out by Historic Scotland on Case Study 4; and the findings are continually disseminated to the public through events (SPAB 2013; Changeworks 2008; Changeworks 2010) .

This shift in policy language is seen across all levels of policy – from the Europe-wide EED down to Local Authority planning requirements, as discussed in Section 2.2.

### *6.5.2 For policy*

Despite the multi-year cycles in politics, policies surrounding energy efficiency, use and generation appear to move at a relatively quick pace. This may be through the drive from international agreements such as those made at the UN's annual Conference of the Parties (COP) events; it may be through European legislation driving UK politics; and it may be through competitive nations attempting to produce legislation that calls for tougher standards than other countries. It has long been established that corporations understand the benefit of good corporate social responsibility, leading to what has been labelled by many as "green wash" or "green bling"; but villages, towns and countries are beginning to realise the potential for a unique selling point for their particular area, in order to strengthen the local economy. Individual towns across the UK aim (and claim) to be the greenest, the most sustainable or the most socially responsible. For example: the UK's first ecotown planned for North West Bicester, Oxfordshire (Cherwell District Council, 2013); Scotland's first bicycle friendly village (VisitNewcastleton, 2013); and BedZED, the UK's first multi-use sustainable community (Zedfactory, 2013). These aims impact on local policy, through setting minimum requirements for energy or carbon reduction in projects through Local Development Frameworks; regional policy – such as the London Plan – adopted by Local Authorities across London; or national policy – such as Planning Policy Statements. Heritage and conservation professionals can be involved throughout the policy preparation, with consultations at each stage of the process to ensure that the concerns of the heritage sector are included.

It can be argued whether a slowdown in house building led to the recession that started in 2008 (BBC News, 2012), or whether the recession was responsible for the slowdown in construction of new homes (Parliament, 2010). The construction industry is still recovering and while it believes it can still meet the policy target of reaching zero carbon homes by 2016 (Zero Carbon Hub, 2013), the recession has slowed down the research, development and application of new materials and technologies that could be applied to both new and existing homes. Therefore, the focus for the UK and Scottish Governments has shifted to the improvement to existing homes.

In all areas of policy, Scotland works in conjunction with the UK Government agencies such as DECC and the DCLG. A key DECC policy also available in Scotland is the Green Deal (Scottish Government, 2012a). This initiative aims to reduce emissions from existing dwellings by providing a loan to homeowners for energy efficiency improvements. The savings made because of the improvements are used to pay back the loan through electricity bills. The loan stays with the dwelling, rather than the owner, so measures with a long payback are not prohibited providing they comply with the ‘Golden Rule’: financial repayments must be less than the modelled savings. These savings are calculated using RdSAP 2009, and there is concern that the methodology could give unrealistic savings (either too high or too low), thus changing the payback time for a loan, and implying an improvement measure does or does not meet the Golden Rule (Ingram & Jenkins, 2013).

The research carried out in this project can be applied to new policy. Primarily, a review of energy assessment methodology with respect to the following is needed:

- Input for occupancy: CS2 has shown that the occupancy calculated using floor area can differ greatly from the actual occupancy. As energy users such as domestic hot water are calculated based on occupancy, the input for occupancy could give unrepresentative results;
- Assessor training: There is a difference in a number of inputs between that which RdSAP allows to be entered in detailed format, and that which RdSAP will allow to be input as a default. Greater confidence in the results would be achieved if assessors were well-trained and therefore able to take educated observations of the dwelling, rather than taking a quick approach when unconfident of their ability.
- Assessment cost: As large companies, small companies and individuals compete for work, the price of an energy assessment to the homeowner decreases. This leads in some cases to the energy assessment being carried out in the least time possible. If there was a minimum price set this could encourage assessors to

spend more time on observations for more accurate inputs. This too would lead to greater confidence in the results of the assessment.

- Technical Guidance update: There are instances in the SAP and RdSAP guidelines where interpretation may differ between assessors (for example, the difference between SAP and RdSAP with respect to main heating systems seen in CS3). There are also differences in interpretation between assessors with respect to the use of local or national climates (Ingram, 2013).

### *6.5.3 For occupants*

The purpose of this research has not been to look at occupant energy behaviour, but the comparisons between predicted energy usage and measured consumption in CS1, particularly electricity, have highlighted that the occupant can be as important as the dwelling itself when considering energy usage and whether a dwelling is performing poorly.

An interesting finding from this research, in both the steady state and dynamic methodologies has been that the internal temperatures are typically far cooler than is frequently suggested as comfortable and healthy by the World Health Organisation (DCLG, 2006). In all the case studies, the internal temperature with heating (according to the steady state RdSAP 2009) was below 17°C during the heating season. It could be suggested from this that the case studies used here are unlikely to reach ‘healthy’ internal temperatures without significant investment or change to the building fabric and/or heating systems and fuels used. An alternative interpretation of this could be that the methodologies are calculating internal temperatures too low and could therefore produce unnecessarily high space heating demands.

Education of the public is a key element in reducing energy demand from existing dwellings, as well as ensuring they are aware of the benefits of their traditionally constructed properties and how best to utilise those benefits. As was found in Section 4.3.1 there is a difference between the SAP rating and the Environmental impact rating. It is the EPC rating that is displayed on property advertisements, but there can be confusion as to why a low carbon technology can be implemented but little change in

EPC rating be achieved. There is also a difference in the display of energy performance certificates between England and Scotland, which could further add to the confusion. Appendix A and B portray the differences.

Whilst it is important that the occupants are aware of the energy used by them, it is also important that any calculation methodology can assess the energy used by the dwelling.

### *6.5.4 For modelling*

One of the arguments for better prediction of energy use is that without knowing where energy is used it is difficult to suggest where consumption needs to be cut. Using an energy assessment methodology which provides only seasonal energy changes (such as steady state methodologies) is not be able to provide that detail. Chapter 5 shows that there is no one methodology that consistently predicts higher or lower energy usage. However it has been shown that the dynamic model, being more sophisticated, enables the assessor to input exact energy usage patterns, and provide occupants with information regarding the fuel usage during those periods, at a scale of hours, rather than months.

While the dynamic methodology may be more detailed, it is not clear from this research whether it is any more accurate than the methodologies currently in use, therefore it is not suggested that any change in assessment methodology be made.

The RdSAP methodology was updated in April 2012 to version 9.91 (v9.91). This allowed local climate information to be utilised in calculations used for cost saving calculations when retrofit options are being considered. In October 2012 v9.91 was amended to include Appendix V, an ‘Occupancy Assessment’. This again is for calculating savings for retrofit options, and involves inputting occupant energy bills and household demographics: the aim being an energy assessment that provides information on where a dwelling is in relation to the national average for a dwelling of its type and age.

### 6.5.5 *For Energy Performance Certificates*

Whilst RdSAP 2009 version 9.91 (although used only for savings calculations and not EPC ratings) is still based on the age of the dwelling, it now also considers the type of dwelling – whether detached, semi-detached etc. The aim of the EPC, besides complying with EU legislation, is to provide a *standardised* method of assessing the energy use of a dwelling. For this purpose, the occupancy of the dwelling should be standardised, as the rating is as much about future occupants as it is about the current occupant. However, while the occupancy assessment recognises that different dwelling types have different energy requirements, it is argued that the results of this research suggest amendments should be made to the EPC process to also consider dwelling type, as an indicator of the area of heat loss.

## 6.6 Justification

This research has been limited to five case studies, and all results are specific to those particular dwellings. To gain conclusions that are more applicable to the Scottish and UK-wide residential stock, additional case studies are needed.

The five case studies were chosen in part for their availability for access, but also because they represent the Scottish pre-1919 dwelling stock. Assessing a tenement flat has shown that it is capable of receiving an EPC rating better than the national average, however a ground floor or top floor tenement, even in the same block as the case study, may receive a worse rating.

In Section 5.1 comparisons were made between the results of the energy assessments carried out for this research and UK average results as shown in the Housing Energy Fact File. It was shown that these five case studies are similar to the UK average energy use for domestic hot water, but that the space heating requirement was much higher than the UK average. It is unsurprising that the DHW figures match, as the figures in the Housing Energy Fact File are calculated using RdSAP, and as DHW is a floor area-based calculation, it stands to reason that these figures would be around the UK average. However, as the space heating requirement was shown – in these five case studies – to be responsible for a higher proportion of energy per dwelling than the national average, it could be said that these traditionally constructed dwellings are more energy intensive than the average UK stock. It is important to recognise that the figures analysed were *percentage* of total energy demand in each dwelling. The research results do not suggest that traditionally constructed dwellings use more energy than the average UK dwelling, rather that of the total energy used in a dwelling; it is likely that the space heating accounts for more than in the average UK dwelling.

The findings of this research are important to all those stakeholders involved in the areas in Section 6.5. The drive to improve the housing stock of the UK to reduce energy use and emissions will most likely see a shift in the way dwellings are used and the energy used to power them. The use of the EPC to set minimum standards on dwellings is an attempt to rid the UK of the worst performing dwellings, and to use market forces to drive the move to a sustainable, low carbon, low energy housing stock. Research into the traditionally constructed and historical dwellings that are of national importance, is the one way to ensure that even those perceived to be the worst performing are considered rationally in the "Knock it down or do it up" debate. Scotland's built environment is a major draw to tourists and a key avenue of income for the country (see Section 2.1), and this research argues that only once accurate, representative and quality assessments of energy are carried out by highly trained and knowledgeable assessors, can the value of the dwellings in question truly be evaluated.

# CHAPTER 7– CONCLUSIONS

## 7.1 Summary

This chapter will discuss in a broader theme the conclusions of the research project. It will recapitulate the key findings and how these relate to other's work, as well as outlining how the initial objectives have been met.

### *7.1.1 Challenges of Scottish traditionally constructed dwellings with respect to energy assessment*

Through the five case study dwellings analysed in this research, conclusions can be drawn that are specific to each case study, but should be extended to the greater Scottish traditionally constructed dwelling stock only with caution.

The challenges faced by traditionally constructed dwellings in energy assessment appear from this research to be similar to the remaining dwelling stock – that of dwelling type. While stone-built dwellings have a public perception problem, they do not necessarily have a problem in gaining good EPC ratings, if there is minimal external heat loss area. Dwellings with large heat loss areas do however suffer within the EPC calculation as the heat loss U-value of the stone walls is so high in comparison with modern methods of construction. The update to RdSAP 2009 v9.91 has addressed this in part, by introducing a factor to apply to the U-value to consider wall thickness and internal finish (BRE, 2012), which for thick (~600mm) walls with a lath and plaster finish improves the U-value from 1.5 to 1.4W/m$^2$K for CS5. Whilst this may not seem significant, over a large external wall, this difference can escalate.

A further challenge for all Scottish dwellings, not just those of traditional construction, is that of the location. The difference in climate between the UK average and the regions defined in SAP across Scotland, results in an under-assessment of space heating demand for an EPC. The research contained in this thesis has provided evidence that local climate should be used for more accurate reporting, and it is hoped that the introduction of using local climate information when calculating savings can be expanded to cover *all* energy assessments.

### *7.1.2 Using steady-state models for energy assessment*

If the aim of progress in energy assessment is to improve precision, then the move from the annual assessment to the monthly assessments used in this research can be seen as a positive step. Any methodology that can recognise seasonal changes in external temperatures and solar radiation should be able to better recognise the demands of a dwelling on energy use. Section 6.2 discussed how the annual methodology consistently calculated a higher space heating demand than its monthly successor. It has not been analysed if this higher value is more accurate when compared with measured data, but the potential reasons for this variance were explored in Section 6.2. It is therefore suggested that the difference between assessments using the RdSAP 2005 methodology and RdSAP 2009 methodology is partly due to the monthly basis of the 2009 assessment methodology, and partly to the calculations within the methodology.

### *7.1.3 Benefits and drawbacks of dynamic simulation*

Whilst carrying out the research, the benefits and drawbacks of the dynamic simulation process were evaluated. Only one methodology – IES Virtual Environment – has been used in this research, and some of the findings here are generic to dynamic simulation, and some specific to the experiences with the IES user interface.

The primary benefit of using dynamic simulation for any dwelling is that it is in-depth. The benefits specific to traditionally constructed dwellings are firstly the inclusion of the thermal capacity of the construction materials in individual rooms and secondly the hourly calculation in the calculation process, which enables a daily diurnal calculation, not just seasonal, as provided by the steady-state methodologies.

The detailed input provides detailed output, which provides a far deeper level of analysis for an assessor to look at *why* a variable has such a value. The figures in Section 4.3.3 are a prime example of the usefulness of such a detailed calculation.

Rather than faith in the answer from a steady-state methodology, a dynamic simulation requires the assessor to analyse the data, interpret it, and on more than one occasion during this research, it was this scrutiny that found errors in the input.

The ease of making an error in the input is the primary drawback of dynamic simulation, as explained in Section 6.1.1. The accuracy of drawing a 3D model into the software even for a simple dwelling such as CS3 requires more time than a complete assessment would take in RdSAP. Additionally, the typical site visit is done with tape measures or sonic measuring devices, neither of which are as precise as more expensive laser mapping technology, and there have been occasions in this research (which would also potentially occur in 'real-world' assessments) where the assessor must make a judgement in the 3D model on what measurement to use, if for example two zones do not meet where the site visit measurements indicate they should. There has been no analysis here on what impact that can have on a dynamic simulation and whether there is a difference in impact on a calculation dependant on whether the zone's dimensions are out by centimetres or millimetres.

There have also been a number of instances in this research where the dynamic simulation methodology has been unable to draw particular aspects of the case study dwellings. This research project has therefore provided IES (through communication with the development team) with the feedback necessary to improve the functionality of their software.

In summary, this research project has identified that the dynamic simulation methodology has great benefit to an assessor who wishes to analyse dwelling energy use in detail and potentially identify key aspects for refurbishment. However, it is also concluded that dynamic simulation may be better suited to new-build dwellings, where detailed dimensional information is available from the architect, and indeed, can be imported directly into the dynamic software. For energy assessment, it has not been found that there is sufficient benefit to suggest that a switch from steady state to dynamic simulation is warranted.

## 7.2 Recommendations

### *7.2.1 Assessors*

Training for assessors of existing buildings should be increased and improved. An energy assessment relies partly on the calculation methodology, but also relies heavily on the assessor. Work completed during an international exchange project at Heriot-Watt University investigated the sensitivity of the RdSAP 2009 (v9.90) methodology to assessor assumptions (Kiehl, 2011). Using the spreadsheet developed for this research project, the investigation found that errors in inputting characteristics could lead to errors in EPC values by two bands – that is a dwelling that should receive a C could receive a B or a D, but not an A or E. There are aspects of an RdSAP assessment that allow the assessor to assume a value (such as level of loft insulation being selected as ‘no access’ when in reality the assessor cuts corners and it may have had good levels of insulation) and this should be better evaluated. Currently, any checks by accreditation bodies on their assessors are made against the information available, as discussed in Section 2.9, but an additional step could be to re-assess the dwelling from the site visit stage, to ensure the correct details are collected. While this aspect is examined at the point of accreditation, which is based on a small number of dwellings, no two dwellings are the same. This would however need approval of the homeowner and may be unworkable.

Also with respect to assessor significance, it was seen in Case Study 3 that the guidelines with respect to heating system selection are unclear. This suggests that different assessors may interpret the guidelines in a different manner to others, leading to variation between results.

Fundamentally, the output is only as good as its input; therefore it is recommended that training for assessors of existing buildings is increased and improved.

### *7.2.2 Climate*

A second recommendation is that the use of regional climate data is extended to cover all energy assessments, not just those used for calculating savings for policy initiatives such as the Green Deal.

### *7.2.3 Occupants*

Public awareness of the interaction between EPCs and low carbon technologies needs to be raised. It was seen between Case Study 3 and Case Study 4 that the application of low carbon technologies while reducing carbon emissions may not reduce cost, ultimately not having a positive impact on the EPC rating. This is in part due to the low efficiency given in the SAP methodology for biomass boilers, and in part due to the higher cost of some biomass fuels. This requires further analysis by those behind the SAP methodology, to ensure that low carbon technologies are not priced out of the market.

Furthermore, there may need to be additional education of the public to be aware of the EPC rating, what it means, and why anomalies such as identified in CS3 and CS4 exist. It is hoped that over the next few years, the number of assessments (whether for sale, let, or energy saving) increase, and with it the awareness of occupants.

## 7.3 Future work

There are certain areas of the SAP methodology and RdSAP assumptions that were not analysed as part of this research project. These could be the basis for further work. In addition, supplementary work has been carried out and is included at Appendix D.

Subsequent investigations could include the social and political impacts as well as calculation methodological changes:

- What impact any policy introducing minimum EPC standards on a property may have on traditionally constructed Scottish dwellings;

- What impact EU Directives (specifically the move from a Renewable Energy Directive to an Energy Efficiency Directive) may have on traditionally constructed Scottish dwellings;
- Further examination of the changes brought in between versions 9.90 and 9.91 of RdSAP with respect to traditional wall U-values and regional climates;
- Analysis of the relationship between heat loss area and space heating demand on a greater number of case studies, with multiples of each type of dwelling (detached, semi-detached, mid-terrace, mid-floor, bungalow, multi-storey etc), and how that relationship differs, if at all, when analysing passivhaus dwellings;
- Extending the work to a much wider range and number of case studies using measured data over at least one calendar year to compare predicted energy demand against measured data, as carried out in this research for Case Study 1.

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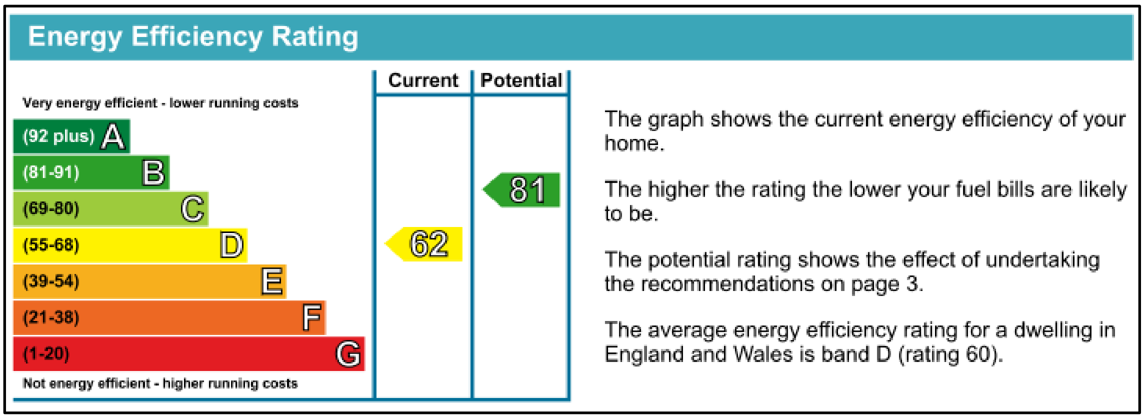
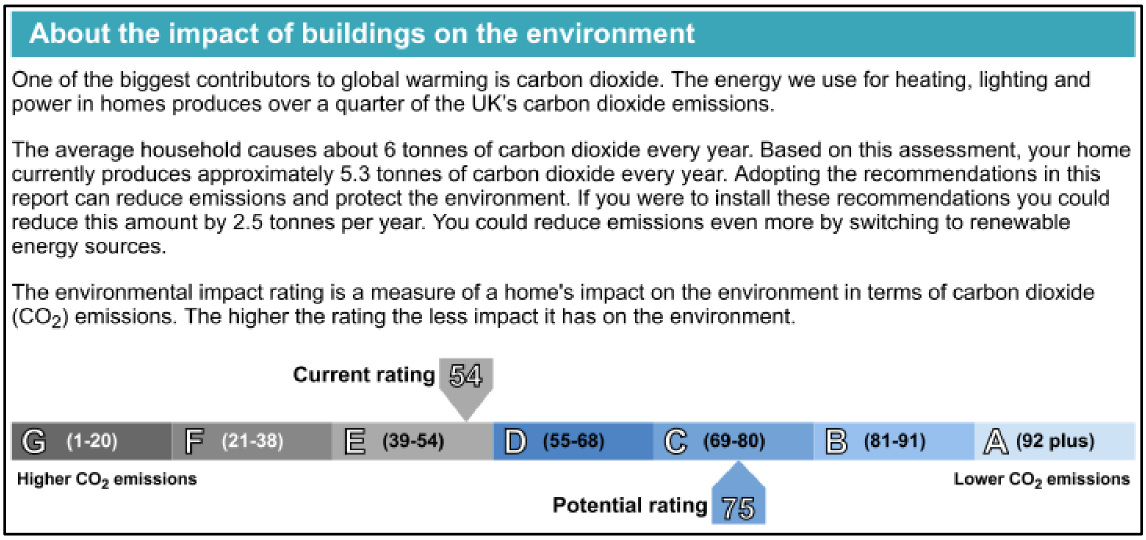
## APPENDIX A

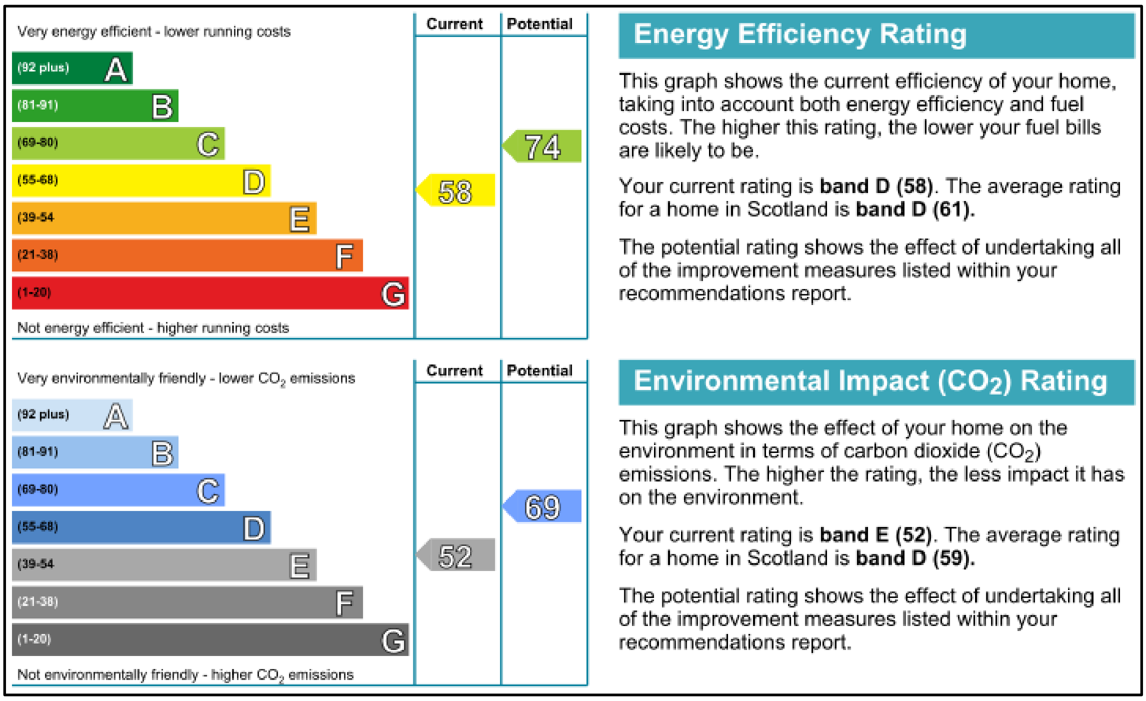



This top image shows a section of the front page of an English EPC from 2012, displaying the Energy Efficiency Rating, also known as the SAP rating. It identifies how the dwelling compares to the national average (without alluding to the dwelling type).

Additionally, on the last page of the EPC, the $CO_2$ emissions are provided, this is the Environmental Impact rating.



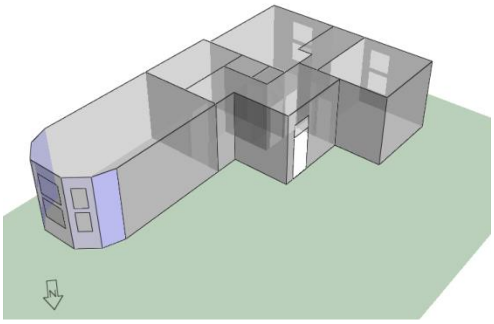
# APPENDIX B




This image is from the front page of a Scottish EPC. Once again the dwelling is compared to the national average irrespective of dwelling type. The difference here is that the $CO_2$ Environmental Impact Rating is shown on the front page, providing the occupant with two rainbow scales, very similar in style.

# APPENDIX C

The following 10 pages contain summary sheets for each case study dwelling, highlighting some key results and comparisons.

| CS1: Stone tenement | 65m$^2$ | Edinburgh |
|---|---|---|
|  |  | |

| | | | |
|---|---|---|---|
| **Description:** | Traditional Edinburgh tenement. Mid floor, mid-terrace.<br>East facing. | | |
| **Age of dwelling:** | ~1900 | **Age band:** | A |
| **Primary construction:** | Solid stone exterior walls, party walls. Suspended floor and ceiling. | | |
| **Glazing:** | Single glazed sash and case. | | |
| **Insulation:** | None. | | |
| **Heating system:** | A-rated gas combi boiler with radiators; programmer and TRVs. | | |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | C | C | C |
| EI rating | 73 | 72 | 64 |
| Space heating cost (£/yr) | 258 | 273 | 335 |
| Mean internal temperature (°C) | 18.2 | 18.7 | 17.45 |

**Summary**

This tenement flat was built during a phase of providing a large volume of new housing to the west of Edinburgh city centre. Being mid-storey and mid-terrace, the flat does not have significant heat loss area, and therefore receives reasonable SAP ratings despite the poor heat loss attributed to the wall construction.

Being in Edinburgh, the space heating requirement appears larger in the location-specific calculation, leading to a poorer SAP rating than a ‘UK average’ based calculation.

The IES model has the lowest internal temperatures and requires a greater level of heating. The difference between actual window orientations used in SAP in comparison to RdSAP’s assumed window orientation is seen in Figure 2.

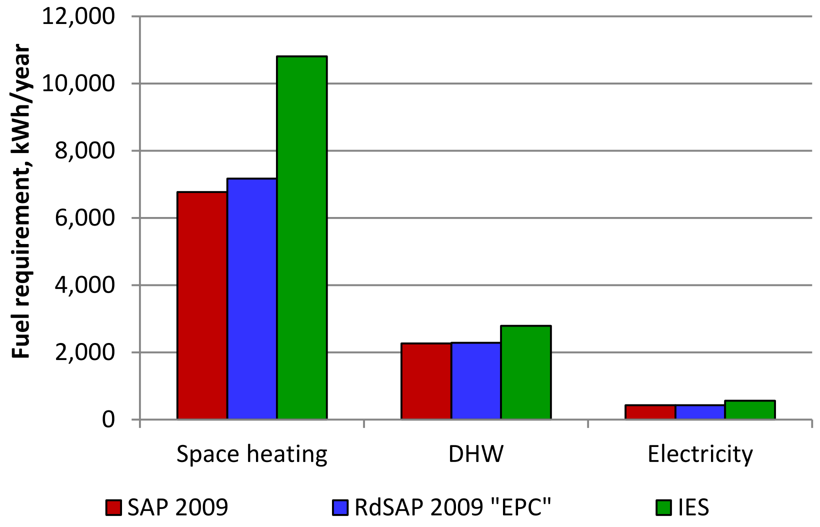



**Figure 0.1. Fuel requirement for one year.**

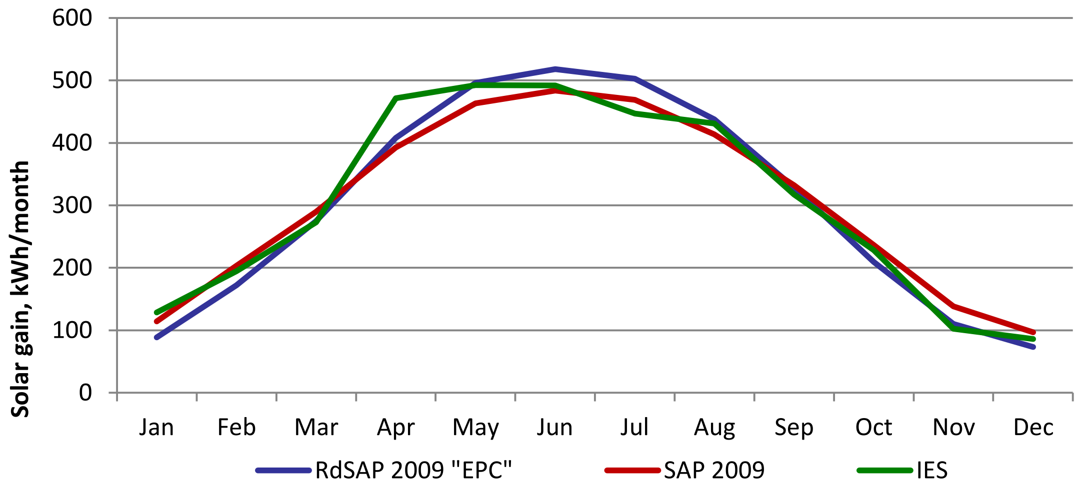



**Figure 0.2. Monthly solar gain. IES and SAP use exact window orientation. RdSAP uses East/West orientation.**

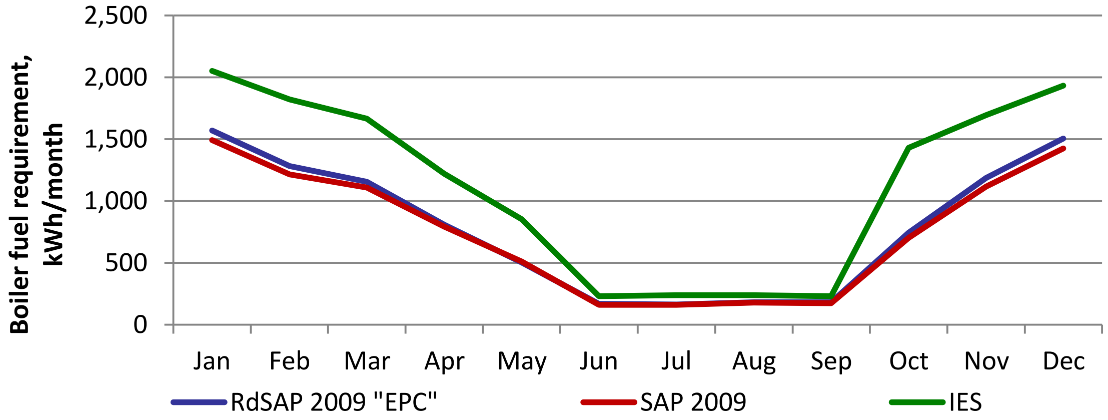
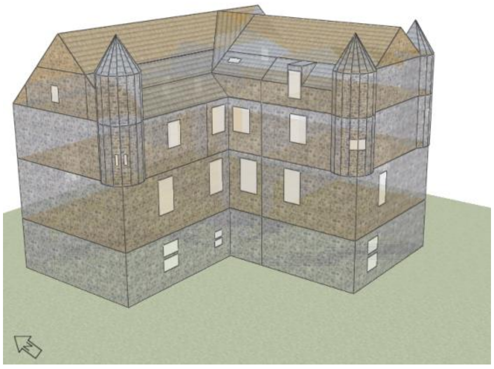



**Figure 0.3. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

| **CS2: Large L-plan detached house** | **361m$^2$** | **Edinburgh** |
|---|---|---|



| | | |
|---|---|---|
| **Description:** | Stone rubble, L-plan, former Laird's house. Detached. Rooms in the roof. | |
| **Age of dwelling:** | ~1600 | **Age band:** A |
| **Primary construction:** | Rubble stone exterior walls; some timber, some brick internal walls. Suspended floors. | |
| **Glazing:** | Single glazed sash and case. | |
| **Insulation:** | None. | |
| **Heating system:** | Two F-rated gas combi boilers with radiators; programmer and TRVs. Additional electric heaters on top floor. | |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | E | F | E |
| EI rating | 31 | 24 | 38 |
| Space heating cost (£/yr) | 3,353 | 3,996 | 2,826 |
| Mean internal temperature (°C) | 16.37 | 16.90 | 15.99 |

**Summary**

This house has a mixed history: having been built mid-16th century and rebuilt following a fire in the 17th; at one point owned by the Earl of Linlithgow and later used as housing for the gardeners at Holyrood Palace; and now used by Historic Scotland as offices.

The house is detached, and being L-plan has significant heat loss area through the 6 external walls, floor and roof. A combination of the poor U-values used in the calculation, the large area, and the poor boiler give very poor ratings.

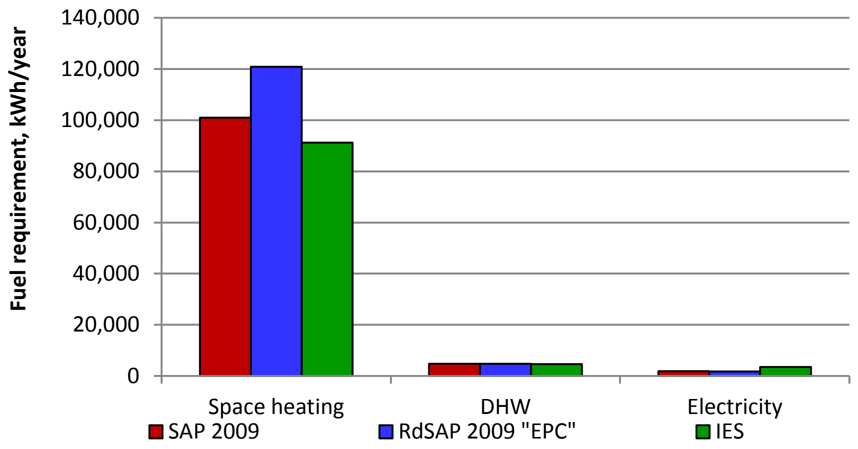



**Figure 1. Fuel requirement for one year. Note the significant space heating demand.**

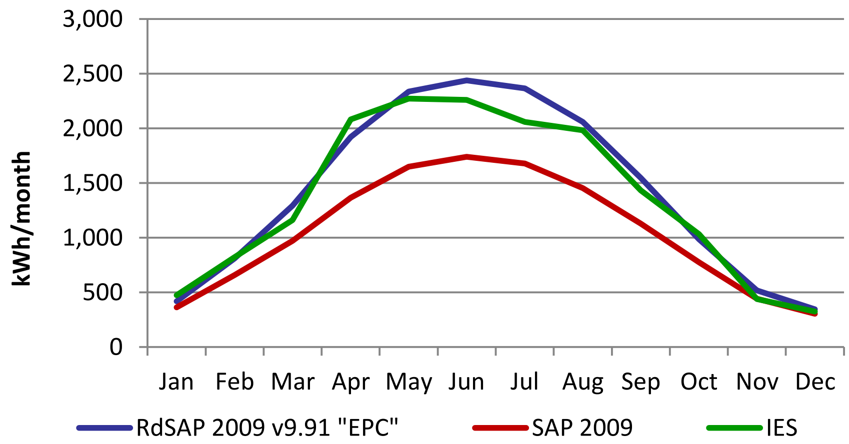



**Figure 2. Monthly solar gain. IES and SAP use exact window orientation. RdSAP uses East/West orientation.**

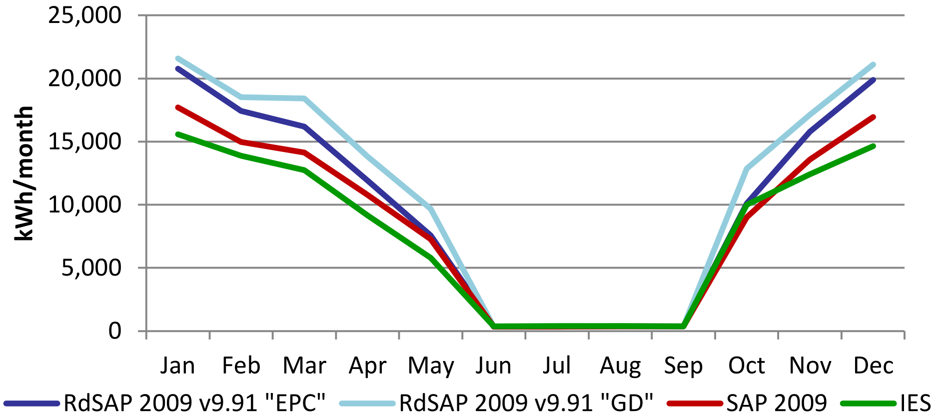



**Figure 3. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

| **CS3: Small cottage** | **$64m^2$** | **Dumfries** |
|---|---|---|

Photo: Moses Jenkins, Historic Scotland

| | |
|---|---|
| **Description:** | Solid stone Garden Bothy.<br>Detached. |
| **Age of dwelling:** | 19th century **Age band:** A |
| **Primary construction:** | Solid stone walls with lath and plaster internal finish.<br>Half the dwelling is timber suspended floor, half is solid concrete. |
| **Glazing:** | Single glazed sash and case. |
| **Insulation:** | None. |
| **Heating system:** | The kitchen has a coal back boiler for hot water; living room uses a coal fire, upstairs uses portable electric heaters. |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | G | G | G |
| EI rating | 16 | 2 | 1 |
| Space heating cost (£/yr) | 1,282 | 1,159 | 1,498 |
| Mean internal temperature (°C) | 15.91 | 17.27 | 15.98 |

**Summary**

The Garden Bothy is a simple 19th century house near Cumnock, Ayrshire, with a two-up/two-down layout. It has recently been used by Historic Scotland as a research property.

The house is detached and as such has high levels of heat loss. The lack of central heating leading to the use of individual room heaters acts to give a poor rating when combined with the high energy requirement for heating. The house faces north with windows only on the north and south facades, revealing the difference between SAP detailed window orientation and RdSAP assumed window orientation (Figure 2).

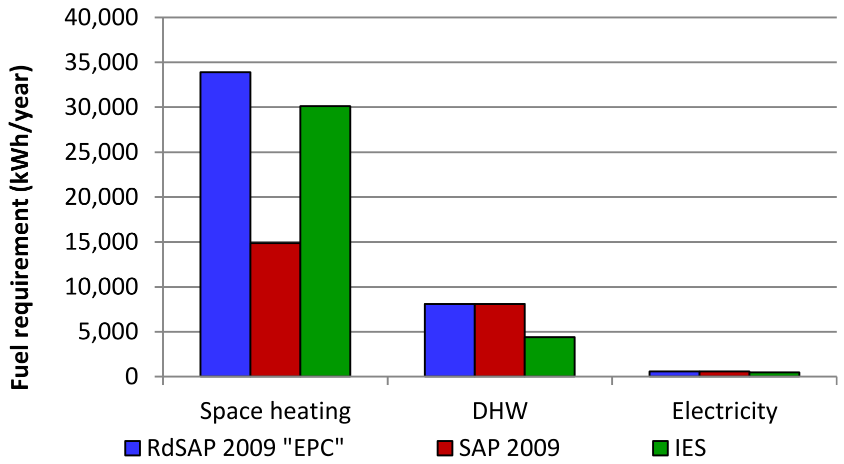



**Figure 1. Fuel requirement for one year.**

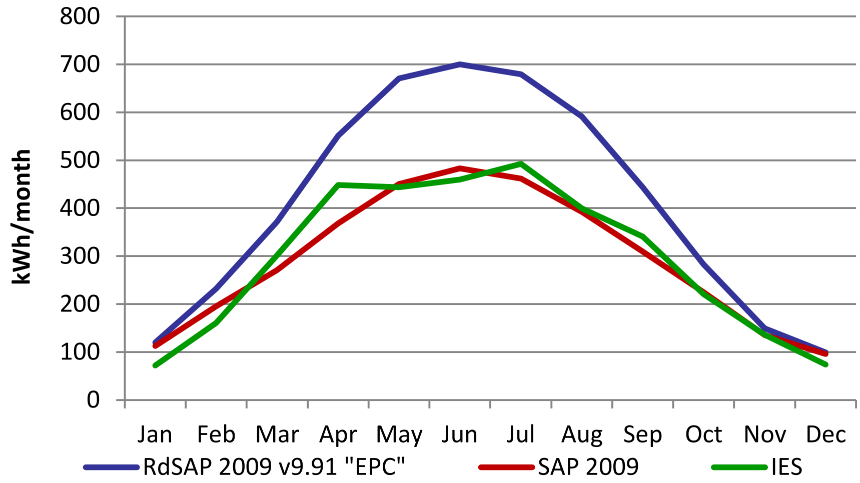



**Figure 2. Monthly solar gain. IES and SAP use exact window orientation. RdSAP uses East/West orientation.**

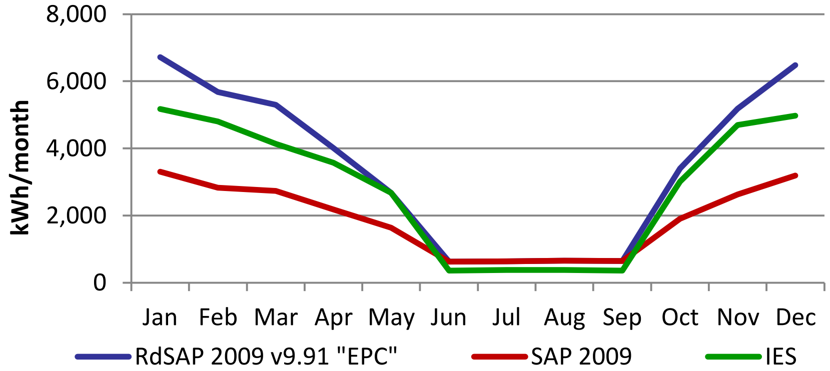



**Figure 3. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

| CS4: Small (refurbished) cottage | 64m$^2$ | Dumfries |
|---|---|---|

Photo: Moses Jenkins, Historic Scotland

| | |
|---|---|
| **Description:** | Solid stone Garden Bothy heavily refurbished to liveable standard.<br>Detached. |
| **Age of dwelling:** | 19th century **Age band:** A |
| **Primary construction:** | Solid stone walls with a variety of internal finishes.<br>Half the dwelling has suspended floors, half has solid. |
| **Glazing:** | Double glazed sash and case fitted in the existing frames. |
| **Insulation:** | *Upstairs*: blown insulation between the external stone and internal lath and plaster finish. Roof insulation added.<br>*Downstairs*: Half lined with hemp-lime mixture, half with insulated clay boards. Insulation added underneath the existing timber boards. Concrete on a bed of clay aggregate and bead insulation replaced the solid floor. |
| **Heating system:** | Biomass central heating system based in the outhouse adjacent to the property; also provides domestic hot water. Immersion available. |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | E | E | E |
| EI rating | 85 | 86 | 92 |
| Space heating cost (£/yr) | 762 | 726 | 573 |
| Mean internal temperature (°C) | 15.91 | 17.27 | 15.98 |

**Summary**

This is the same dwelling as in CS3. Historic Scotland has investigated the potential for energy refurbishment that is sympathetic to the building; CS4 recognises these real life refurbishments.

The house is detached and as such has high levels of heat loss. Each aspect of heat loss has been dealt with using a number of developing technologies (see “Insulation” above). The introduction of central heating should improve the thermal comfort of occupants, with consistent temperatures throughout the dwelling. The use of biomass is a low carbon fuel, and significantly improves on the Environmental Impact rating seen in CS3.

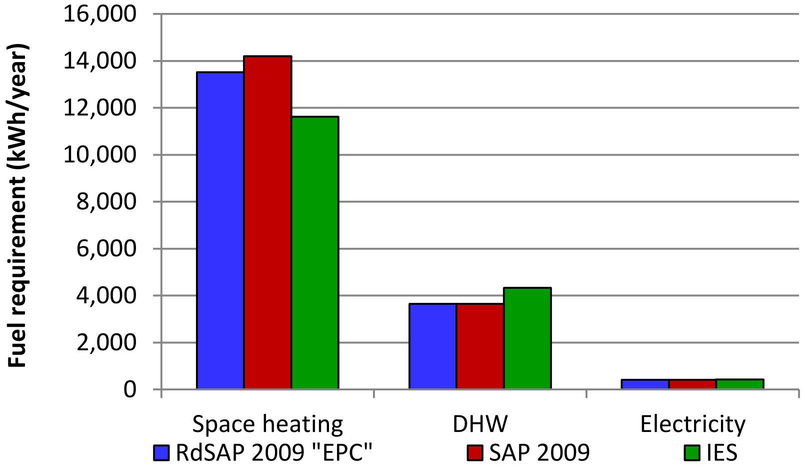



**Figure 1. Fuel requirement for one year.**

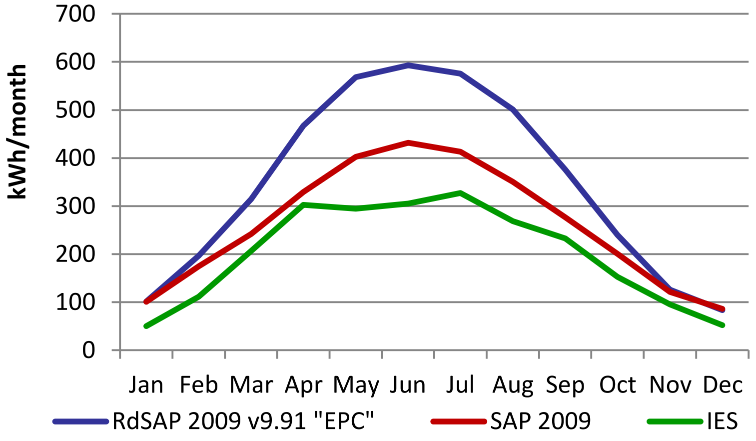



**Figure 2. Monthly solar gain. IES and SAP use exact window orientation. RdSAP uses East/West orientation.**

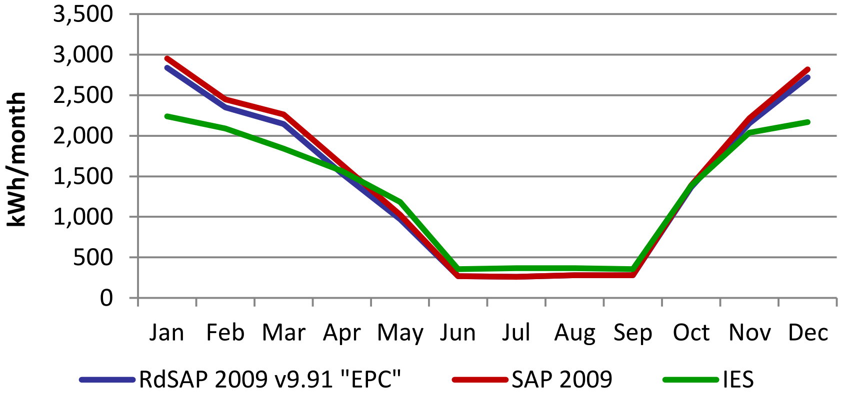



**Figure 3. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

| CS5: Small semi-detached cottage | 48m² | Edinburgh |
|---|---|---|

| | |
|---|---|
| **Description:** | Solid stone single storey cottage with brick extension to the rear. Semi-detached. |
| **Age of dwelling:** | ~1895 **Age band:** A |
| **Primary construction:** | Solid stone walls with plasterboard internal finish. Suspended timber floor, slate roof. |
| **Glazing:** | Double glazed sash and case in all but one window, which is single. |
| **Insulation:** | 240mm mineral wool foil-lined quilt in the roof. Cavity wall and floor insulation added to extension. |
| **Heating system:** | D-rated combi boiler with programmer, fuelled by bulk LPG tank (off gas-grid), feeding radiators with TRVs. |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | F | E | F |
| EI rating | 51 | 54 | 39 |
| Space heating cost (£/yr) | 704 | 645 | 871 |
| Mean internal temperature (°C) | 17.39 | 18.18 | 17.34 |

**Summary**

This bungalow was built at the end of the 19th century as housing for farm labourers in a village just west of Edinburgh. Part of a larger development at the time, it is one of only two that have survived, the remainder having been rebuilt after falling into disrepair.

The village is off the mains gas grid, therefore the cottage uses bulk LPG. The LPG is delivered automatically when the tank reaches a certain level, but there is no way of knowing the LPG usage until the bills arrive annually. The electricity is on a pre-pay system, the only case study to use this method of electricity payment.

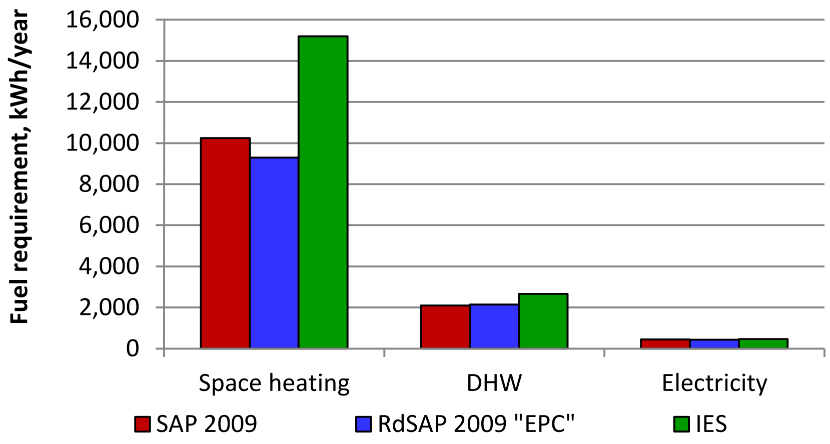



**Figure 1. Fuel requirement for one year.**

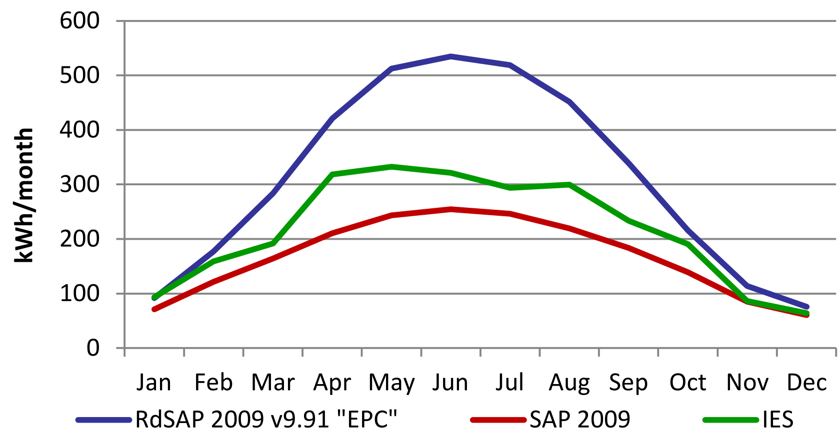



**Figure 2. Monthly solar gain. IES and SAP use exact window orientation. RdSAP uses East/West orientation.**

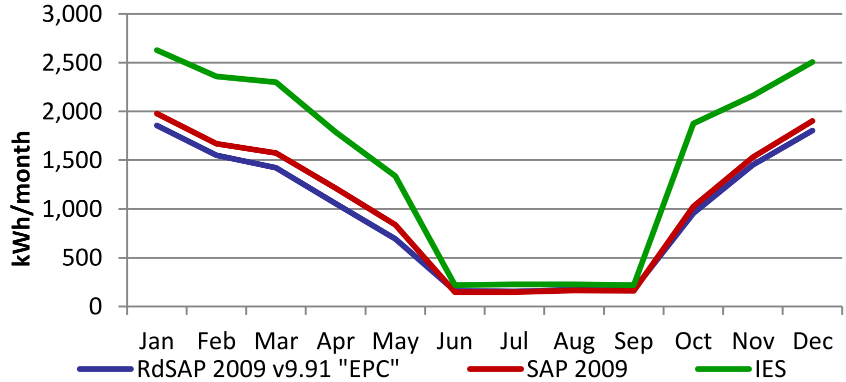



**Figure 3. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

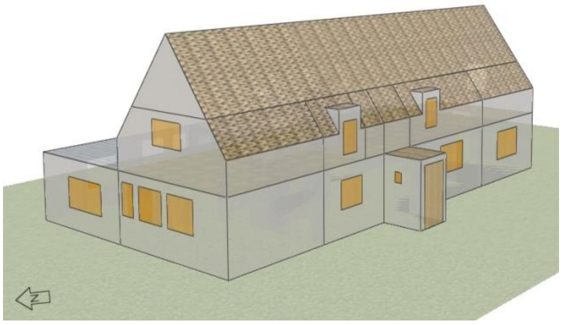
# APPENDIX D

Four additional case study dwellings have been assessed for energy use as part of a follow-on project, also funded through EPSRC and supported by Historic Scotland. The steady-state methodologies used are the Standard Assessment Procedure (SAP) version 9.90, traditionally used for new-build properties, and the Reduced data Standard Assessment Procedure (RdSAP) version 9.91, used for existing dwellings. Also used was the dynamic simulation software IES Virtual Environment.

The following pages show similar summary results as in APPENDIX C, but with the added calculations carried out for assessment under the UK's Green Deal. This calculation, unlike the assessment for an EPC, uses regional climate data to calculate energy requirement. Under a Green Deal assessment, a number of refurbishment technologies have been assessed to ascertain potential savings, and measured against the 'Golden Rule'. This states that the loan repayment (calculated here with an interest rate of 7.5%), paid back over no more than 20years, must be less than the annual savings calculated by RdSAP.

The work was published by Historic Scotland (Ingram, 2013) and presented (Ingram & Jenkins, 2013).

| CS6: Large thatched house | 191m$^2$ | Suffolk |
|---|---|---|



| | | | |
|---|---|---|---|
| **Description:** | Timber frame traditional English farm cottage with 1970s extension. Detached. | | |
| **Age of dwelling:** | 17th century | **Age band:** | A |
| **Primary construction:** | Wattle and daub walls with lime wash internal finish. Thatched roof. Extension has solid floor, block cavity walls, and insulated slate roof. | | |
| **Glazing:** | All windows wooden frame single glazed. | | |
| **Insulation:** | No insulation on sloping ceilings. No cavity wall or floor insulation. | | |
| **Heating system:** | Unrated (obsolete) oil boiler (off gas-grid), with programmer feeding radiators with TRVs. Hot water from an oil-fired AGA. | | |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | F | F | F |
| EI rating | 33 | 30 | 26 |
| Space heating cost (£/yr) | 1,823 | 1,955 | 2,022 |
| Mean internal temperature (°C) | 16.36 | 17.14 | 17.88 |
| **Green Deal Assessment (baseline)** | | **RdSAP 2009** | |
| SAP rating | | F | |
| EI rating | | 32 | |
| Space heating cost (£/yr) | | 1,879 | |
| Mean internal temperature (°C) | | 17.21 | |

**Summary**

The heart of this traditional English farm cottage was built in the 17th century, with additions made in the 18th and 19th centuries, making the cottage longer. In the 1970s a single storey extension was added to the rear of the property. The house is now Grade II listed and off the gas grid, restricting the potential refurbishment and technology options.

With thin walls in the main dwelling and cavity walls in the extension, the detached nature of the property gives it high heat loss. Combined with the inefficient and expensive oil boiler the property receives a poor rating on the EPC. Anecdotal evidence from the occupants suggests the use of the AGA reduces the heating requirement, as it warms the house, although this also encourages the occupants to use only the warmest parts of the house, restricting the quality of life.

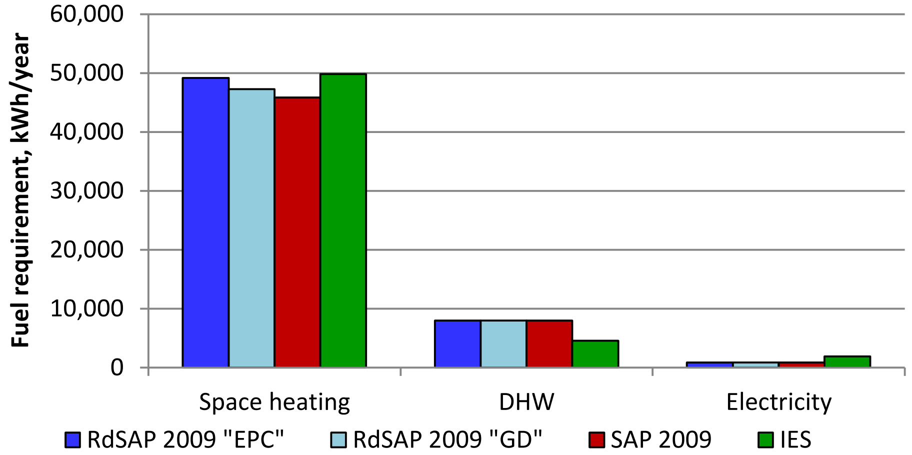



**Figure 1. Fuel requirement for one year.**

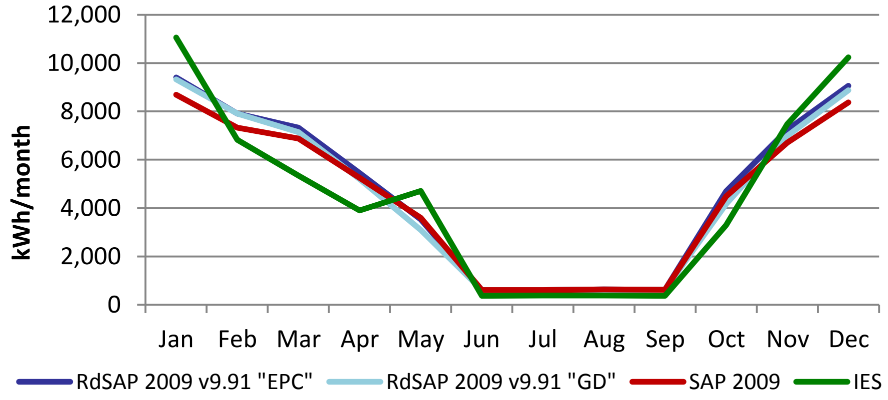



**Figure 2. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

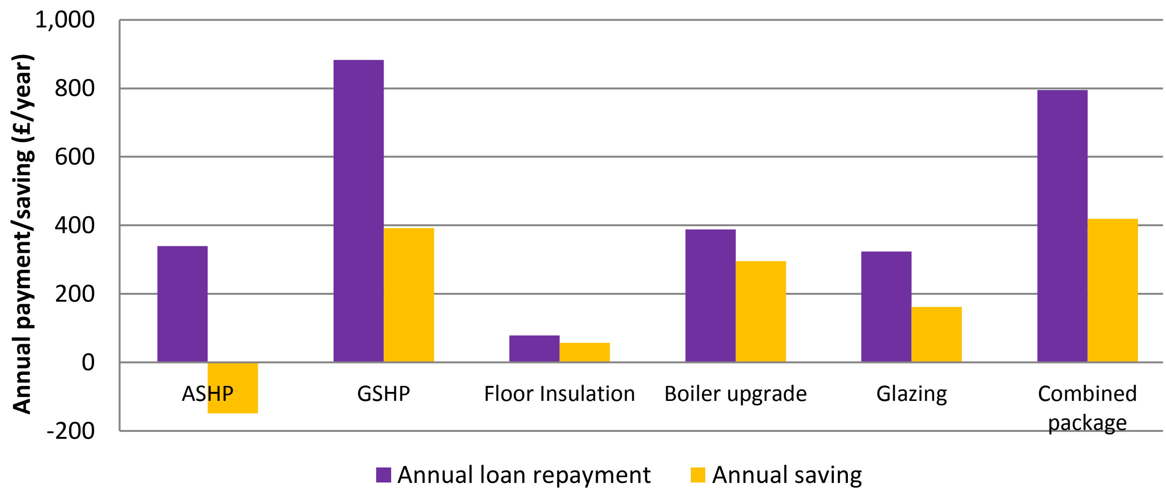



**Figure 3. Potential energy saving measures specific to CS6 as calculated through RdSAP 2009 v9.91. The savings of the higher efficiency ASHP are offset by the higher costs of electricity when compared to oil. No measures here meet the Golden Rule.**

| CS7: Large detached house | 240m$^2$ | Essex |
|---|---|---|

| | | | |
|---|---|---|---|
| **Description:** | Timber frame traditional English house with 1980s extension plus 2002-built garden room. Detached. | | |
| **Age of dwelling:** | 15th century | **Age band:** | A |
| **Primary construction:** | Main: Wattle & daub walls, timber floor, clay tile roof;<br>1980s extension: cavity brick wall, timber floor, clay tile roof;<br>Garden room: timber walls, timber floor, clay tile roof. | | |
| **Glazing:** | All windows wooden frame secondary glazing. | | |
| **Insulation:** | No insulation on sloping ceilings. Floor and wall insulation only in garden room. Roof insulation where practical. | | |
| **Heating system:** | Biomass boiler in outhouse for heating a thermal store that combines with output from two solar thermal panels. Second main source of heating is a C-rated oil boiler used in the winter when needed. | | |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | E | E | G |
| EI rating | 78 | 74 | 29 |
| Space heating cost (£/yr) | 1,781 | 2,243 | 3,501 |
| Mean internal temperature (°C) | 15.53 | 16.25 | 18.56 |
| **Green Deal Assessment (baseline)** | | **RdSAP 2009** | |
| SAP rating | | E | |
| EI rating | | 75 | |
| Space heating cost (£/yr) | | 2,143 | |
| Mean internal temperature (°C) | | 16.35 | |

**Summary**

The main dwelling of this former farmhouse was built in the 15th century, with additions made in the 16th, late 20th and early 21st century. The house is Grade II listed and off the gas grid, restricting the potential refurbishment and technology options.

The detached nature and thin walls of the majority of the house give this dwelling a high level of heat loss. The occupants are actively seeking to reduce their energy consumption and carbon footprint, and have temperature sensors in the four main spaces used, as well as zonal time and temperature control of the radiators. Measured oil consumption and internal temperatures are available for a full 12 month period.

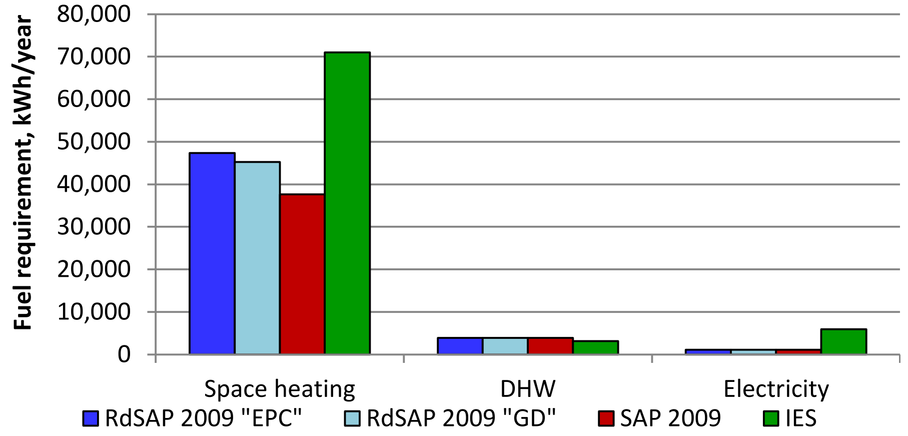



**Figure 1. Fuel requirement for one year.**

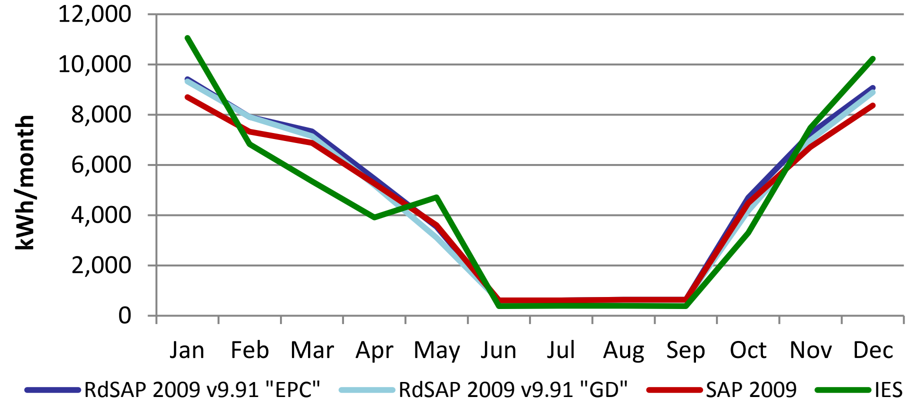



**Figure 2. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

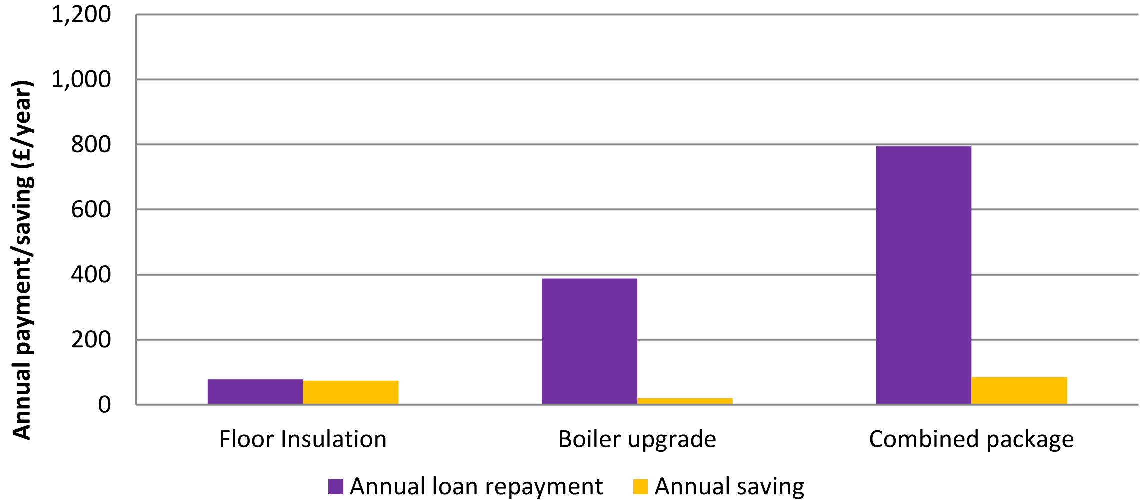



**Figure 3. Potential energy saving measures specific to CS7 as calculated through RdSAP 2009 v9.91. Greater savings than costs indicate a successful measure which meets the Golden Rule. There are few options available to the dwelling, with solar water and biomass heating already utilised as well as secondary glazing.**

**CS8: New build 3rd floor flat** | **61m²** | **Edinburgh**

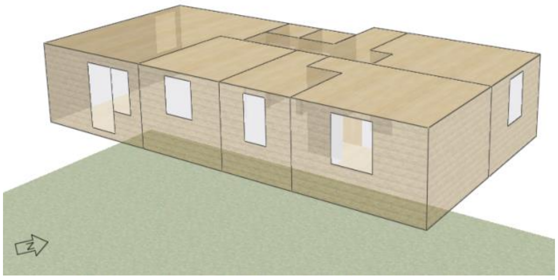


Photo: Google Street View

| | |
|---|---|
| **Description:** | New-build semi-detached flat in high rise development. Flats below, above and on north side, with heated corridor. |
| **Age of dwelling:** | 2006 **Age band:** J |
| **Primary construction:** | Steel frame, with filled cavity block wall and stone cladding. |
| **Glazing:** | All windows double glazed uPVC. |
| **Insulation:** | Insulation in cavity in walls. Exact details unknown. |
| **Heating system:** | A-rated combi condensing boiler serving radiators and hot water system. Programmer and TRVs. |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | C | C | B |
| EI rating | 82 | 83 | 82 |
| Space heating cost (£/yr) | 144 | 176 | 92 |
| Mean internal temperature (°C) | 19.73 | 19.98 | 20.51 |
| **Green Deal Assessment (baseline)** | | **RdSAP 2009** | |
| SAP rating | | C | |
| EI rating | | 81 | |
| Space heating cost (£/yr) | | 84 | |
| Mean internal temperature (°C) | | 19.93 | |

**Summary**

This flat is part of a large redevelopment of a brownfield site in the West of Edinburgh. The flat faces south, and while it has three external walls it benefits from flats above and below minimising heat loss, and also benefits from a heated corridor which further reduces heat loss. The minimal heat loss, level of insulation, and age of building (dwelling required to meet 2003 Building Standards) provide the flat with a good SAP rating.

Being part of a block of flats reduces the availability of roof space for solar technologies, and what alternative heating systems could be used. For example, a low-carbon biomass system would be impractical in an individual flat, however a district heating system for the block (or the development) would be relevant, although potentially difficult to install as a retrofit. The wall cavity is already filled, further reducing the range of Green Deal measures applicable to this dwelling.

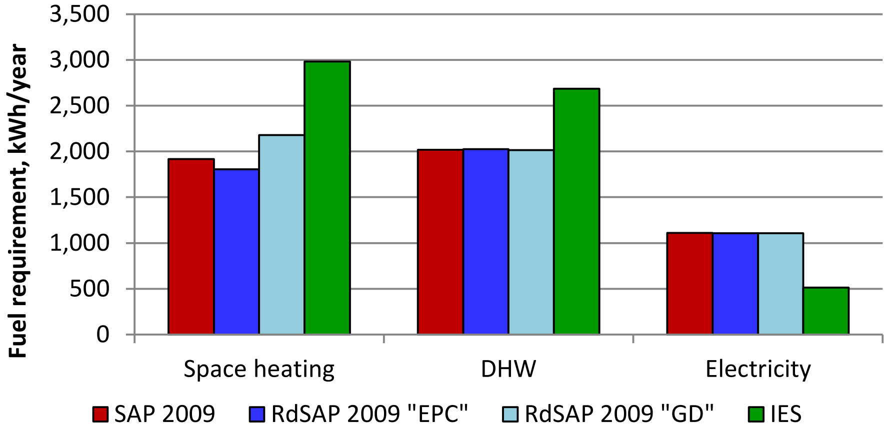



**Figure 1. Fuel requirement for one year.**

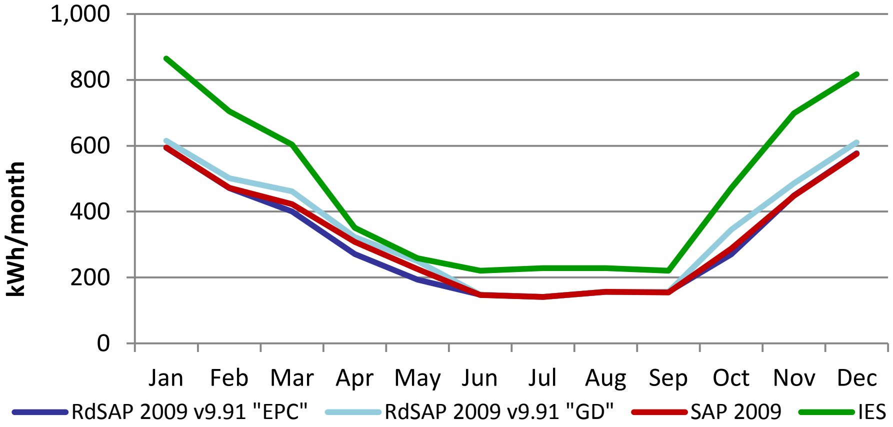



**Figure 2. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

**As CS8 is a new-build flat, calculations for the Green Deal are unsuitable for the following reasons:**

- The flat has been built to relatively recent Building Standards and as such already has low thermal transmittance through the walls, double glazing, and a high efficiency boiler;
- Each block of flats in this development has approximately 20 flats and a share of any solar (PV or thermal) would be small. Additionally, the roof design is unsuitable for solar technology, with a flat roof on the east half and an inverse slope on the west half that would limit winter afternoon sun;
- The current boiler is A-rated and any improvement in efficiency would be by 1 or 2% only.
- As the flat is mid-floor, there is no opportunity to improve loft or floor insulation;
- The introduction of room thermostats to the heating controls does not reduce the heating requirement in the model, as it is labelled the same 'control type' as the existing controls.
- The storage and delivery of solid fuel to a mid-floor flat prohibits individual heating systems such as biomass.
- Communal heating systems have not been considered or modelled in this research.

| **CS9: 4-in-a-block flat** | **77m$^2$** | **Edinburgh** |
|---|---|---|

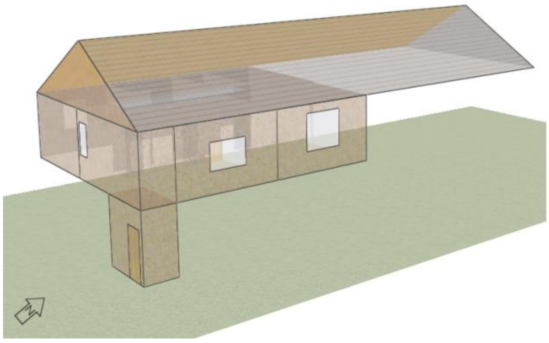


Photo: Google Street View

| | | | |
|---|---|---|---|
| **Description:** | Upper level maisonette-style flat. Recently refurbished. Semi-detached. | | |
| **Age of dwelling:** | 1940s | **Age band:** | C |
| **Primary construction:** | Solid brick wall, solid floor, tile roof. | | |
| **Glazing:** | All windows double glazed uPVC. | | |
| **Insulation:** | 260mm mineral wool in the loft. | | |
| **Heating system:** | D-rated combi condensing boiler serving radiators and hot water system. Programmer and TRVs. | | |

| **Energy Performance Certificate Assessment** | **SAP 2009** | **RdSAP 2009** | **IES** |
|---|---|---|---|
| SAP rating | D | D | E |
| EI rating | 57 | 65 | 41 |
| Space heating cost (£/yr) | 619 | 491 | 736 |
| Mean internal temperature (°C) | 18.37 | 19.13 | 16.79 |
| **Green Deal Assessment (baseline)** | | **RdSAP 2009** | |
| SAP rating | | D | |
| EI rating | | 63 | |
| Space heating cost (£/yr) | | 536 | |
| Mean internal temperature (°C) | | 18.97 | |

**Summary**

This flat is part of a suburb of Edinburgh added post-WWII as council housing on the site of a former estate. During refurbishment, a newspaper dated 1944 was found, suggestive of the original build date.

The flat has adjacent flats below and next door so heat loss is reduced, but there are significant areas of wall and roof through which heat is lost, hence a ‘good practice’ level of loft insulation. A poor boiler contributes to the rating which while average for the UK, is lower than might be expected of a flat.

The flat would benefit from a new heating system – either a more efficient gas boiler, or an alternative source such as a heat pump, combined with greater controls such as room thermostats. As the roof belongs to the property, solar technology could also be utilised in the dwelling.

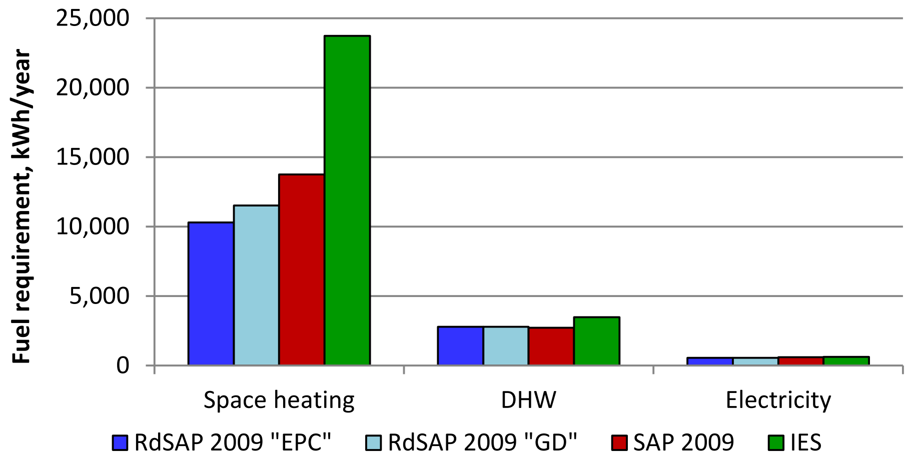



**Figure 1. Fuel requirement for one year.**

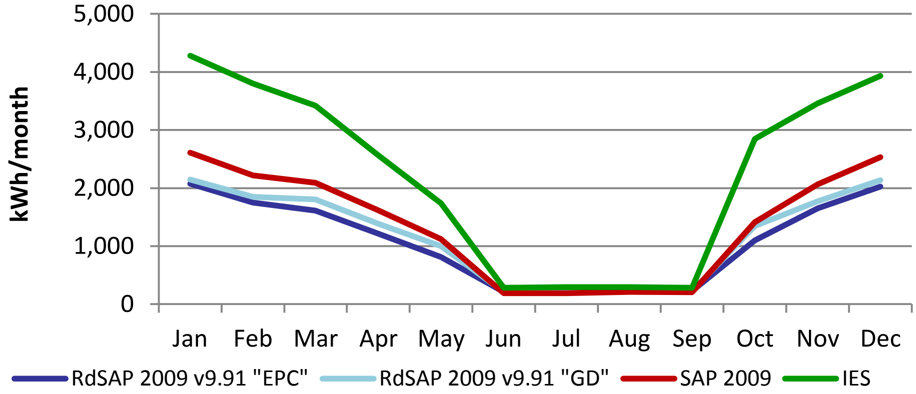



**Figure 2. Energy requirement for space heating and hot water, taking into account distribution losses and system efficiency.**

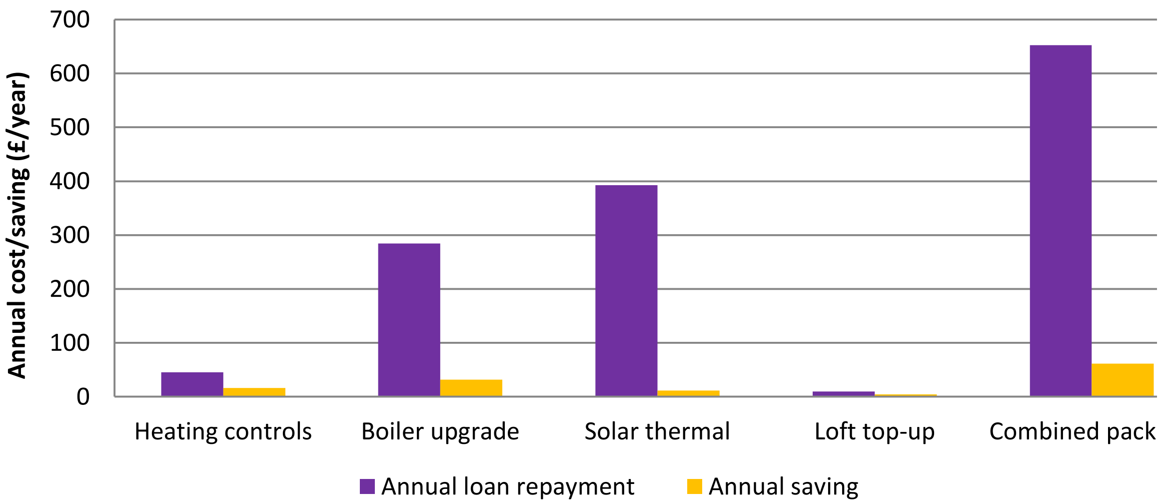



**Figure 3. Potential energy saving measures specific to CS9 as calculated through RdSAP 2009 v9.91. Greater savings than costs indicate a successful measure which meets the Golden Rule. These measures do not meet the Golden Rule.**